IMPACT

of science on society

UNIVERSITY OF MICHIGAN
PRR
1956
PERIODICAL READING ROOM

Vol. VI, No. 3
September 1955

[A] Price per copy: $ .50; 2/6; 125 fr.

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IMPACT *of Science on Society*
quarterly

Annual subscription:
[A] $1.75; 9/6; 450 fr.

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NS 55 I 20A

UNITED NATIONS EDUCATIONAL, SCIENTIFIC
AND CULTURAL ORGANIZATION
19 Avenue Kléber, Paris-16e, France

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THE DUALITY OF SCIENCE: KNOWLEDGE AND ACTION

by

PIERRE AUGER

Former Director of Higher Education in France, Professor of Physics at the Sorbonne, and discoverer of the compound photo-electric effect and of the extensive atmospheric showers of cosmic rays (both of which bear his name), Professor Auger is now Director of the Department of Natural Sciences at Unesco.

During the nineteenth century it became necessary to make a distinction, in many branches of science, between basic research and research conducted with a view to its immediate practical application. The terms 'pure' and 'applied' science, which are most often used in drawing this distinction, have been rightly criticized, but no better epithets have yet been suggested. It has been pointed out, for instance, that to talk of 'pure science' implies the existence of impure science, and that if there is 'applied science', science that cannot be applied presumably also exists. Moreover, such a distinction may well lead to the arbitrary separation of spheres of science which should remain closely connected, and to their being allotted very different places in the social system; it may thus seriously hamper the harmonious advance of the great enterprise of adapting man to the universe and the universe to man, which is the distinguishing feature of the modern world.

It is perhaps both truer and more constructive to say, with Pasteur, that there is really no applied science but only applications of science. Science thus retains its fundamental unity, and the duality of pure and applied science is resolved into the duality of knowledge and action. We are thus led to make a more exact analysis of the relationship between 'knowing' and 'doing', so as to place our conception of the human value of science on a sounder basis.

Let us consider what happens when a research worker in the field of pure science tackles a new problem—for instance, when he tries to explain a phenomenon observed by chance, such as the darkening of a photographic plate through the action of uranium salts. After careful reflection, he will work out an hypothesis and then embark on a series of calculations and theoretical work. This stage of his research is perhaps the only one which can be considered really 'pure', since it proceeds from thought alone. Very soon, however, he will have to put his entire theory to the test of experiment, and this marks the beginning of the practical phase of research. The scientist

will have to act upon the universe in order to direct the course of events; he thus ceases to be a thinker pure and simple and becomes an engineer; he constructs apparatus, calculates the resistance of his materials and the electrical properties of his circuits, invents ingenious devices to secure the conditions he considers necessary. In many cases, he will stumble on inventions, some of which, when adapted to industry, may lead to important economic developments. At what point can applied research be said to have begun? Was it when the research worker 'applied' his ingenuity to setting up the crucial experiment which confirmed or disproved a theory? Or did it begin only when the aim of technical development became to produce an instrument of commercial value?

If the pursuit of knowledge may lead to action, the intelligent conduct of action may also result in knowledge of new laws. Take the discovery of the second law of thermodynamics. Carnot, who was an engineer, was concerned with the 'motive power' of fire, but his thinking on this subject led him to establish one of the most abstract principles of physics, and one of those which have had most implications in the sphere of philosophy and, indeed, of metaphysics.

It may be instructive to observe that in the history of each of the great branches of science, there are successive periods when the two aspects of knowledge and action are relatively close and relatively distant in their connexion with each other. In its early stages, knowledge has not acquired sufficient accuracy to serve as a basis for useful action, and the man who devotes himself to the observation of natural phenomena and their theoretical interpretation can offer only negligible assistance to the craftsman or technician who has to carry out the practical work of the community. At a later stage of development, when scientific knowledge proper has become sufficiently sure of itself, its bearing on technical problems becomes so obvious that no one would dream of drawing a distinction between science and its application. This was what happened during the period when the great techniques of mechanization were beginning to transform Western industry.

However, such close contact between science and its application does not, as a rule, last very long. The phenomena in which scientists are interested, once they have explored the domain immediately within man's reach, lie in spheres more and more remote from everyday life. The science of mechanics, for instance, forsaking the solids and fluids that make up objects on the same scale as ourselves, has reached out, on the one hand, to the planets and the stars and, on the other, to the atoms and their nuclei. That is the point at which we begin to be conscious of the essential duality of knowledge and action, a duality concealed during the previous period because action followed immediately upon knowledge, and the same men who advanced the one were also responsible for applying the other.

It is also at this stage in the development of science that it is most dif-

ficult to interest industrialists, members of parliaments, and government officials in 'pure' scientific research. Such people are usually quite prepared to encourage the application of science but, in most cases, cannot understand that the discovery of a new particle in cosmic rays could in any way affect output and the cost of production. It is admittedly difficult to make clear the connexion between concepts apparently so remote from each other, but the task is not impossible and is worth attempting; for such an attempt, if successful, may sometimes exert a great influence on the rhythm of scientific progress.

It would therefore be most desirable to bring out more clearly the various aspects of the close connexion between research undertaken for the purpose of adding to our knowledge and the technical progress which is the great historical fact of modern times. While it is scarcely feasible to carry out 'pure' research without resorting to continual applications of science—necessarily utilitarian in character, however 'pure' the aim in view—there can, on the other hand, be no prospect of new applications of science except on the basis of continually progressing knowledge. Once this interaction is recognized, we still have to find the right human or even social machinery to enable both types of research to develop as harmoniously as possible.

To guide our efforts in devising this machinery, it may be helpful to employ a comparison taken from biology. The discoveries by which our knowledge is advanced, and which become an integral part of our traditional heritage, may be likened to mutations in the genetic heritage of living creatures. The technical applications to which these discoveries give rise, modifying as they do the economic and social conditions of human communities, would then be comparable to the 'somatic' or physical changes in living creatures resulting from these mutations. The relationship between the mutation, which is simply a chemical change in a gene, and the character of the living adult being is not immediately comprehensible, although there is no doubt that it exists; it is to be found in the mechanism of development about which we still know practically nothing. In our comparison, the train of technical improvements and elaborations represents this development. Conversely, natural selection, which operates only among living creatures, favours those bearing useful mutations, and thus prepares the ground for new progress. In the same way, we must create a favourable soil for new discoveries in pure science by associating with the successes of applied science the scientists, and the laboratories in which these discoveries may originate.

In biology, the gulf between the genes, subject to mutation, and the living creature, able to benefit from contact with the outside world, is bridged by substances such as hormones which, as it were, transfer the old or new characters of the genetic heritage for the benefit of the developing cells and organs. It is this biochemical mechanism that leads from knowledge (genes)

to action (development). A similar mechanism might perhaps be envisaged in the case of science. Finally, one of the most striking features of mutations is their independence as regards the consequences they will have in the course of the development. 'In nature' said Gide, 'there are no problems; there are only solutions.' Perhaps the same should apply to research, and indeed, do we not see every day that the discovery of penicillin was not a consequence of the search for new medicaments, any more than the discovery of nuclear fission resulted from research for the exploitation of new sources of energy?

The ideal would be, firstly, to ensure that working conditions in laboratories are the best possible, while at the same time preserving the independence essential to success, and, secondly, to set in motion the train of study and development by which alone the progress made in the sphere of pure science can lead to practical technological application. As regards the reverse influence—that of progress in applied science on pure science—it must remain as subtle as the influence of natural selection; by which I mean that it must favour the fields in which progress seems most useful, without exercising at the same time any pressure whatsoever on the direction this progress should take.

Let us now consider in greater detail what we may call the social system of science and of its applications; it will then be easier for us to devise machinery that will bring into play the various influences we have just described.

The requirements for rapid progress in the basic sciences may be summed up as follows: good staff, good equipment, efficient exchange of information. Arrangements must be made in each country, on a national level, to satisfy the first two requirements; a national scientific research council or centre should be set up, comprising committees of scientists responsible for selecting research workers according to their scientific qualifications, and for determining the best allocation of the available funds and premises. To fulfil the third requirement, i.e. the exchange of information, international machinery is needed for acquainting research workers with the results of work in other laboratories which may have an important bearing on the conduct of their own research. Generally speaking, learned societies, international unions, congresses and discussion meetings, and the various more or less specialized journals meet this need. In short, suitable financial arrangements, good recruitment policy and active interchange should be enough, in present circumstances, to ensure the satisfactory progress of pure research.

On the other hand, as regards progress in the field of applied science, general committees, similar to those which may work well in the basic sciences, are not enough. The problems raised by technological development are too numerous and too specialized to be satisfactorily covered by

such committees, and it is therefore necessary to consider establishing *ad hoc* committees on a temporary basis to discuss particular technical questions of acknowledged urgency; such committees should include representatives of industry and of the production organizations of the nation, in general. These committees would then decide on the action to be taken, either by the public authorities or by private interests prepared to meet the cost of carrying out the necessary research work. Whereas the general committees in the sphere of pure science are concerned with the advance of our knowledge, the specialized committees here described must constantly aim at practical and economic successes. Here again the questions of finance, recruitment and information are of the greatest importance. The machinery differs from that described in the case of pure science in that it is temporary and specialized, and closely connected with production organizations. These differences also have an effect on the criteria governing the selection of subjects and methods of work.

Let us now consider the arrangements for liaison between these two systems of committees and laboratories, whereby the type of influence described above may be brought to bear. The exchange of papers and reports is obviously the first stage. It must, of course, be reciprocal exchange, for while technicians are bound to base their work on the findings of scientists, the latter in their turn would deprive themselves of powerful aids if they did not keep abreast of the latest technological improvements. Liaison machinery based on publications alone, however, will not suffice. Personal contacts are necessary because, through them, the 'pure' scientists can exercise a much profounder and more thorough influence upon technicians, while applied science, in return, can make its contribution to research. If this were not so, nations which are newcomers to science—as the United States of America was in the nineteenth century—might concentrate on forms of applied scientific research particularly useful to themselves in the early stages of their development, and be content, as regards progress in pure science, to read the publications of the 'old countries', that is, the countries of Europe. It is a well known fact, however, that it has proved necessary to set up centres for basic scientific research in mathematics, physics and biology in the new countries themselves, so as to avoid a slowing down of technological progress. Papers are not enough; even visits by specialists and personal contacts at congresses and symposia, though extremely useful, are not in themselves a satisfactory solution. What is needed are permanent, daily, contacts.

These remarks, obvious at the international level, also apply at the national level. Once they have published their results, university laboratories often think that they have done all that is required of them, and pass on to other types of research. Technicians put a product or a piece of apparatus on the market with no other thought than the profits to be derived from it.

It seems to me that new life could be infused into the essential exchanges between these two groups by establishing a special staff of liaison officers, with the following three distinct functions:

1. To conduct a challenging, indeed aggressive, information campaign among the directors of pure science laboratories, in order to supply them with particulars of technical developments in the field of applied science. The object would be not only to meet requests from scientists, but to take the initiative, making them offers similar to those put forward by commercial travellers to arouse the interest of prospective clients. Though this system may perhaps involve research workers in laboratories in some slight waste of time, it will often have the advantage of awakening new ideas in their minds.
2. To give meetings of the specialized committees concerned with applied science lively and challenging reports on results observed during visits to pure science laboratories, results that may have a bearing on the solution of the technical problems dealt with by the committees.
3. Outside the discussions of the committees themselves, the members of the liaison staff should prepare reports on all interesting cases, pointing out the connexions they think they have discovered between technical problems and the results of work in pure science. These reports would be addressed to the organization in charge of scientific research and might give rise to two types of action on its part:
   (a) a new specialized committee might be set up to carry out the suggested chain of practical application;
   (b) special working facilities (grants-in-aid, equipment, staff, premises) might be offered to scientists dealing at the time with the problems of pure science involved in the chain of practical application. It is clear, however, that the encouragement of pure science research in any field where it has been recognized that practical application, even if remote, will be useful, must not in any way imply direction but only an increase in working resources.

The liaison staff considered here must have special qualities, enabling them both to appreciate the importance of advances in pure science and to foresee the possibilities of application, even if these sometimes lie far in the future. Imagination and the capacity for abstract thought are perhaps less important here than a well-developed sense of reality, or rather, of what is practicable. At the same time, however, these liaison officers will need very open minds in order to give serious consideration to the most unlikely contingencies and to evaluate them by reason alone, without allowing prejudice or habit to stand in the way. They should not let themselves be carried away by ill-judged enthusiasms, but should always be ready to accept without incredulity the possibility of very great technical changes. They will probably need, from time to time, to immerse themselves again in pure science or in techno-

logy proper, so as to preserve their capacities. The best age for these officers would be between 30 and 45, since their qualities of imagination and maturity must be well balanced.

If such a system is to work satisfactorily, it is obviously necessary that certain kinds of decisions be taken, within the organizations in charge of scientific research, by an executive body, which may be a council, a directorate or a standing committee. The available financial resources for instance, should be allocated among the pure science committees in accordance with the proposals of this body, although this should not imply any intervention in the selection of subjects for research. Where research in applied science is concerned, however, the central authority should have a say in the choice of subjects, having regard to the practical and specialized character of the research committees.

There are still two aspects of the relationship between pure and applied research to be dealt with—the financial aspect, and what I may call the 'secrecy' aspect.

The financing of research work is one of the major responsibilities of the executive authority, whatever form this authority may take; and also one of the most difficult to carry out. Pure research is generally much less expensive than applied research, except in certain modern branches of astronomy or physics. But what little is needed is needed much more urgently, for without it everything else is liable to come to a standstill. One method of providing more or less automatically for reasonable funds to be placed regularly at the disposal of pure science, without regard to the immediate results expected, would be to allot it a fixed percentage of the sums devoted to applied research. An industrialist or a ministry undertaking technical development work would be required to pay a kind of tax—say, 10 per cent or 15 per cent—for pure scientific research in general. It is most important that the amounts thus made available should not be earmarked, by the organization which pays them out, for research on too narrowly-defined subjects: just as direction is desirable in applied research, so freedom is desirable in pure research. The ideal would be to pay the income from this tax to the central body responsible for pure research, which would allocate it in accordance with its usual rules among the various specialized committees.

Finally, we come to the very controversial question of the secrecy of certain types of research, and of the disastrous effects of such secrecy, even though it may often be inevitable. In the first place, it is clear that secrecy, whether prompted by military or commercial considerations, throws out the whole machinery for the reciprocal exchange of information described above. It makes it necessary to split up research workers into small groups or teams knowing nothing of one another and simply reporting to a higher authority. In certain industrial research laboratories even temperatures have been

recorded on a special secret scale, different from Centigrade, so that the very technicians responsible for the measurements may not be able to pass on the results to anyone else! All organizations carrying out research for practical purposes should realize, however, that the basis of lasting strength must be the ability to make progress. Strength based only on secrecy, like that of the fortified castles of old, must always yield sooner or later to a new invention. And, as the practice of secrecy militates against progress, we must make our choice. From the intellectual point of view, one of the greatest evils of secrecy is the resulting duplication—and sometimes triplication or more—of effort. At great cost in time and money, France does what has already been done in the United States of America and in Britain. How can research workers be expected to be enthusiastic about their work when they are morally certain that their colleagues in other countries, unknown to them, are carrying out the same experiments, and thus very probably making their labours unnecessary?

But let us not dwell on this depressing prospect, which should not last for ever, since it is merely the symptom of a social sickness. Mankind will recover its health, and all scientists are morally bound to help it in that return to reason.

POPULATION GENETICS AND THE STUDY OF MAN

by
JEAN SUTTER

Dr. Sutter, Head of the Qualitative Studies Service at the Institut national d'études démographiques, Paris, is the author of several works, including L'Eugénique, *Paris, 1950. He has also conducted research on the effects of consanguinity and endogamy, on the structure of isolates and on genetic mortality.*

Population genetics is something that has grown out of the probability concepts of Mendelian genetics. However, before we can define the genetics of population and the problems within its orbit, some explanation of the technical terminology of Mendelian genetics is required.

The gene theory was introduced into genetics as a result of Mendel's initial research on the inheritance of well-defined characters. It is as if these characters were transmited by organic particles distributed among the reproductive cells in accordance with simple laws. Morgan and his followers later demonstrated that these particles, called genes, are localized in the chromosomes of the cell nuclei. Each gene occupies a specific position (locus) in a specific chromosome. The sex cells or gametes have a haploid constitution, that is, each of their loci is occupied by a different gene. The sum of genes in the male gamete (spermatozoid) constitutes the paternal genom, while the genes of the female gamete (ovule) constitute the maternal genom.

The fusion of two sex cells gives rise to an individual, or zygote, with a diploid constitution, whose loci are arranged in pairs, one carrying a maternal gene and the other a paternal gene. These homologous loci may be occupied by two similar (*AA* or *aa*) or different (*Aa*) genes or alleles. Individuals having the first combination are said to be homozygotes, while those of the second type are said to be heterozygotes. The particular gene structure constitutes the individual genotype, while the phenotype is its morphological manifestation.

As sex is determined by a particular chromosome, all the genes carried by this chromosome are said to be *sex-linked* and all the genes in the other chromosomes are said to be *autosomic*. To understand what follows, one should be acquainted with some of the terms characterizing the various possible crossings. For instance, monohybrid diallelism denotes combinations arising from crosses between individuals whose characteristics are determined by two different genes (diallelism) belonging to one pair of alleles (monohybridity). (The examples given below will illustrate the character of mono-

hybrid diallelism.) Monohybrid triallelism denotes the existence of three different kinds of genes, only two of which may be present at the same time in the zygotes. The situation is more complicated if there are two active pairs of alleles and two different genes in each pair; we then have polyhybrid diallelism. Polymeric diallelism is another type of crossing of interest for the human species. It is characterized by a varying number of active pairs of alleles, each gene having the same effect as the others. They may replace one another without bringing about any appreciable difference in individual characteristics. Each of the crossings described above may be adapted to particular conditions, e.g. sex-linked heredity, dominance, recessivity, etc.

To give some idea of the problems studied in population genetics, let us take the case of heterozygous individuals *Aa*. They produce two types of gametes (*A* and *a*) which on fertilization give rise to three types of zygotes, *AA*, *Aa* and *aa*. One of the objects of population genetics is to find out what happens to these three types of individuals through successive generations.

A certain proportion of these three types of individuals is to be found in the population at any given moment and for any given generation. This proportion may be altered by such factors as celibacy, sterility and premature death, which result in one generation not being entirely reproduced in the next. The purpose of population genetics is to establish mathematical models explaining how the gene will develop from one generation to the other under the influence of the decisive factors coming into play.

EXAMPLE OF A GENETIC MODEL

With sexual reproduction, each generation is renewed by the combination of the sex cells (gametes) produced by individuals of both sexes in any given generation. In the human species the reproductive cells may be said to combine at random, like the drawing of lots from two different boxes; there is no need to stress how meaningful this fact may be for the theory of population genetics. The construction of models is further simplified if the characteristics of the population are defined artificially on the basis of certain hypotheses. Panmixia, for instance, is a general hypothesis of vital importance in the development of population genetics. Its three main assumptions are that: (a) the population is closed—meaning that no migrations (immigration and emigration) take place in it; (b) marriages are made at random; i.e. there is no choice of the mate nor are there any marriages between blood relations; (c) fertility is identical for all couples; there is no differential fertility; in other words, families all have the same number of children, regardless of their social class.

On the basis of this working hypothesis, shortly after the rediscovery of Mendel's laws, the first mathematical models were constructed. They mark

the beginnings of population genetics; one of the first and most important steps taken was the elaboration of the so-called Hardy's formula, which may be illustrated as follows.

Let us take the case of the *A* and *a* alleles in an insular population whose geographical situation favours panmixia. According to Mendel's law of segregation, the offspring of a cross between an individual who is a homozygote with respect to *A* (*AA*) and an individual who is a homozygote with respect to *a* (*aa*) will include *AA*, *Aa* and *aa* individuals in the following proportion: 25 per cent of *AA*, 50 per cent of *Aa* and 25 per cent of *aa*. Among these individuals the *A* and *a* alleles have the same frequency (50 per cent) and each sex produces an equal number of *A* and *a*. If there is random mating between these individuals, it can readily be seen from a simple algebraic formula that the individuals of the following generation will be distributed in the same proportion, namely: 25 per cent of *AA*, 50 per cent of *Aa* and 25 per cent of *aa*. The same will be true of the succeeding generations. We can therefore assume that the genetic structure of a panmictic population does not vary from one generation to the next. If we take p as the initial proportion of *AA* individuals and q as the proportion of *aa* individuals, then $p + q = 1$, or the entire population. If this formula is applied to the foregoing data, it can easily be shown that the proportion of individuals of the three categories in the first generation arising from *AA* and *aa* is equal to p^2, $2pq$ and q^2 respectively. In the second and third generations, the frequency of individuals will remain the same—p^2, $2pq$ and q^2.

We have so far been concerned with individuals. But the frequency of the *A* and *a* genes and of the gametes carrying *A* and *a* will also be found to be identical. In the type of population considered above, the formula p^2, $2pq$, q^2 is thus still applicable to gametes and genes. This model of Hardy's formula has other properties but these will not be dealt with here.

Hardy's formula thus has two main implications. Our foregoing remarks have been concerned with autosomic genes, that is, all genes except those carried by the sex chromosome; these autosomic genes are inherited in virtue of monohybrid diallelism. The model should conceivably become more complex with any change in the type of inheritance. For instance, it should be possible to construct adequate models for sex-linked heredity, dominance or recessivity, dihybrid diallelism, polymeric diallelism, etc., taking account of each particular mechanism. We may thus arrive at mathematical formulae which are often highly complex but shed most valuable light on the processes taking place in actual populations.

These models may serve as a basis for the definition of population genetics, which has been described by G. Malécot[1] as follows: 'It is the sum total of mathematical models which can be constructed to represent the evolution of

1. G. Malécot, 'La génétique de population: principes et applications', *Population*, 1955, 10, p. 239-62.

the structure of a population classified in accordance with the distribution of its Mendelian genes.'

Criticism of the concept of panmixia has produced another line of development in population genetics. The factors on which this hypothesis is based can obviously only seldom be met with in human populations. It departs from reality because of the following factors:

1. Selection or differential fertility: for one reason or another, individuals carrying a particular assortment of genes are unable to reproduce themselves, or at least have a lower-than-average fertility.
2. Consanguinity: for one reason or another, mating takes place between an appreciable number of blood relations.
3. Choice of the mate: in the population there is a systematic choice of the mate, which means that the proportion of marriages between individuals with a given character is higher than would be the case with random mating.
4. Mutations: one or more genes undergo mutation at a given moment in one or more individuals; the nature of the gene or genes is thus modified, as also is its equilibrium in the population.
5. Migration: there is a certain amount of immigration and emigration.
6. Lastly, account must be taken of the numerical size of the population and its limits.

It is quite possible for random marriages to take place in both small and large human groups; yet there is a basic difference between the two. The distribution of genotypes becomes stable in the course of time if the human group is sufficiently large. However, if it is small, this distribution is modified from one generation to the next, as we shall see subsequently. It is also understandable that in very small human groups there is a far greater likelihood of rare genes disappearing as the result of chance (genetic drift).

It would be possible to construct mathematical models in which panmixia was mitigated and corrected by the factors of reality. Here again the formulae are sometimes complicated; but they are enlightening. Ph. L'Héritier's definition of population genetics would then be valid: 'This is the science which is concerned with the genetic structure of various types of population and its possible variations from one generation to the next under the impact of the factors listed above' (those listed under the preceding six points).[1]

Population genetics may seem a profitless study at a first perusal of works on the subject, and the mathematical apparatus necessary for formal research has often been considered remote from reality. In fact, nothing could be less true. Population genetics already has outstanding successes to its credit. There has often been striking agreement between reality and theoretical assumptions in respect of a wide variety of animal species. In the case of

1. Ph. L'Héritier, *Traité de génétique*, Paris, 1954.

man, the truth of theoretical data has been borne out very closely in many fields. Most revealing is the comparison between observation and calculation for blood groups. The following table, compiled by Wiener, illustrates the remarkable agreement between the theoretical and the observed frequency of blood groups M and N in different human populations. This is one of the triumphs of Hardy's formula.

Calculated and observed frequency of blood groups M and N in different human populations (Wiener)[1]

Number of individuals	*Population*		*Percentage of blood groups*			*Frequency of alleles*	
			M	*MN*	*N*	P^{MN}	Q^{MN}
6,129	Whites (U.S.A.)	Observed	29.16	49.58	21.26	0.540	0.460
		Calculated	29.16	49.58	21.26	—	—
278	Negroes (U.S.A.)	Observed	28.42	49.64	21.96	0.532	0.468
		Calculated	28.35	49.89	21.86	—	—
205	Amerindians (U.S.A.)	Observed	60.00	35.12	4.88	0.776	0.224
		Calculated	60.15	34.81	5.04	—	—
569	Eskimoes (E. Greenland)	Observed	83.48	15.64	0.88	0.913	0.087
		Calculated	83.35	15.89	0.76	—	—
504	Ainos (Japan)	Observed	17.86	50.20	31.94	0.430	0.570
		Calculated	18.45	49.01	32.34	—	—
730	Australian aborigines	Observed	3.00	29.6	67.4	0.178	0.822
		Calculated	3.17	29.26	67.57	—	—

1. From C. Stern, *Principles of Human Genetics*, San Francisco, 1949.

Spectacular as it may appear, it is not this aspect of population genetics with which we shall be concerned in this paper, but rather the implications that the models described may have for the social sciences. These models shed much new light on the development and future of the species; they have already been responsible for the revision of conceptions which had seemed to be firmly established; and they are opening up new vistas. It is now possible to obtain a wide variety of exact measurements that should be of immense benefit to research in history, sociology, anthropology, ethnography, etc. This paper will be confined to a few general examples.

CONCEPT OF THE ISOLATE

Marriage customs are naturally of prime importance in studies of population genetics, which are mostly concerned with the pattern of distribution of the gametes. This has important demographic and sociological implications. A thorough analysis of the marriage rate and its various attendant phenomena was necessary to provide a firm foundation for research. For convenience of calculation, the Swedish geneticists Wahlund and Dahlberg[1] coined the term 'isolate' to define the population group within which the individual is able to find a mate.

Life in Europe before the industrial age affords a good illustration of the truth of this concept. A whole set of factors—including the difficulty of transport and the frequently open hostility between one village and another—limited the prospects of marriage to the same extent as among primitive tribes or geographically isolated communities today. The first idea which springs to mind in connexion with the mechanism of the formation of isolates is thus bound up with geography; but the decisive factor may be entirely different. The cult of two different religions in the same geographical area automatically creates two isolates; and many isolates are formed by the co-existence of two racial groups. Furthermore, in all countries there is frequent intermarriage between families sharing the same professional interests—artists, musicians and doctors. This practice has something in common with the caste system, the chief creator of isolates.

For the sciences of man, the primary interest of the concept of the isolate is that we can measure its size, or, in other words, the number of individuals from among whom it is theoretically possible to choose a mate. Although this is a field in which we cannot hope to obtain absolutely reliable data, and measurements are only approximate, it is important that they can be made, as there is all too great a tendency to theorize from hypothetical data. As early as 1929, Dahlberg showed that the size of the isolate can be estimated from the frequency of marriages between first cousins.

This quantitative evaluation is based on the existence of a close connexion between the size of the population and the frequency and distribution of the various degrees of family relationship. When the choice of a mate is limited by the shortage of marriageable individuals, we may, if there is random mating, expect to find a large number of unions between close relatives; hence the idea of measuring the size of the isolate from the number of marriages between first cousins. Léon Tabah and the author showed that it would be better to base estimates on the number of marriages between second cousins.[2]

1. Cf. Dahlberg, *Mathematical Methods for Population Genetics*, Basle, 1948.
2. J. Sutter and L. Tabah, 'Les notions d'isolat et de population minimum', *Population*, 1951, 6, p. 481-98.

In any case, if we are to grasp the full significance of this measurement, account must be taken of an important demographic factor—the average fertility rate of the population under consideration. The frequency of marriages between relatives of a given degree depends on the average size of the family. For instance, an individual from a group in which families have an average of two children would, on the average, have two uncles or aunts (third degree), four first cousins (fourth degree), six cousins once removed (fifth degree) and eight second cousins (sixth degree). The corresponding figures for families with an average of seven children are 12, 84, 346 and 588. Of course, not all these relations are marriageable, owing to incompatibilities of sex or age. As the average size of the family increases, so does the distance between relatives' ages, and a number of marriages are impossible in normal circumstances. Thus, of the 588 second cousins that an individual of the last group considered might have, half must be ruled out as being of the same sex, and, of the other half, some will be too widely separated by age for marriage to be possible. Calculation shows that age differences may become so great that marriage is impossible between a great many of the relatives from families with an average of over five children.

Dahlberg estimated on the basis of his calculations that in the pre-industrial period in Sweden the average isolate must have consisted of approximately 400 persons, while the figure today is probably 1,600. Unfortunately, we have very few exact data for the present size of isolates in Western and other countries. The author has published data covering two French departments as a whole and a number of communes in those departments. For instance, in the Loir-et-Cher Department it was found that, between 1919 and 1950, the size of the isolate increased from 1,620 to 5,400. For the Department of Finistère the corresponding figures were 1,500 and 4,000. In the same period, the figures for all the 12 most endogamous communes of the Loir-et-Cher Department were 270 and 810, while for the 10 most endogamous communes of the Department of Finistère they were 1,060 and 2,100.

We shall not dwell on the important biological implications of this concept, nor on the services it has rendered to population geneticists. But, as we shall see, its implications go beyond the biological or medical sphere. Research in this field soon raises sociological issues.

The important present-day characteristic of isolates is their process of chronological growth, which has been aptly described as their 'break-up'. Isolates do, indeed, seem to have been constantly increasing in size for a certain period, the beginning of which has been arbitrarily situated in the nineteenth century. We have shown that in France this is apparently a more recent phenomenon, since the world wars seem to have played a decisive part in this connexion. The break-up of isolates, both as regards speed and extent, may be measured from the drop in marriages between blood relations.

This phenomenon, which is a good index and yardstick of an important aspect of social change, in that it affords a concrete measurement of a far-reaching change in the marriage-rate, has not yet been adequately explained. At least the explanations so far put forward are not entirely convincing. Economic change over the past century is given as the main reason. It has resulted in increased transport facilities and constant migrations, etc.; but the fact that the break-up of isolates is a more recent development shows that the problem is more complex. It obviously reflects a deep-rooted change in society and customs that can be satisfactorily explained only by a thorough sociological study. In Western countries this is mainly a question of rural sociology, but urban sociology may also benefit greatly from such studies.

It was soon apparent to the students of isolates that urban and rural isolates have widely differing social structures. Hitherto it was thought that marriages between blood relations were a thing of the past in the big modern towns. This assumption was based on the following argument: the general decrease in the number of marriages between blood relations over the past thirty years, added to the fact that such marriages were once rather rare in big towns, suggested the belief that they must no longer exist nowadays. This is quite untrue. The percentage of marriages between blood relations during the period 1861-74, in Paris, was 1.22 per cent—a figure which, according to our inquiry conducted 65 years later, had by then risen to 1.25 per cent.[1] Making allowance for minor inaccuracies, it can therefore be estimated that the fall-off, if any, in marriages between blood relations in the cities has been trifling as compared with the substantial decreases observed over the same period in rural areas. We can, therefore, assume that isolates in the big towns have a permanent, well-defined character, although little is known about the way they arise and are perpetuated.

The foregoing comments are sufficient to show that pure genetic research soon leads to a solution of sociological problems. This, although of secondary importance for our present purpose, should not make us overlook the fact that the very concept of the isolate may provide the social sciences with a tool of great value by clearly defining the fields of investigation open to a wide range of specialists. Religious, anthropological, ethnographic and cultural problems may yield to precise solution—which a few years ago would have been thought impossible—thanks to the exactitude with which they may be defined and to the principles of measurement which will provide a check on research results at every stage. To clarify our meaning, we shall merely cite two results obtained recently through the use of this method. S. F. Cook, studying intermarriage between Amerindians and whites in the United States of America, has demonstrated that cultural factors have outweighed physical characteristics in this phenomenon. He calculated that this

1. J. Sutter and L. Tabah, 'Fréquence et répartition des mariages consanguins en France', *Population*, 1948, 2, p. 607-30.

trend will lead to the complete disappearance of the Amerindian isolates of California within a century. This process should take five times as long with other tribes, where intermarriage has been a slower development. Studies carried out in France by M. Maget on an Alpine village constituting a typical isolate showed that its break-up was due to migration. Since the mid-eighteenth century, the migrants have always passed through the same valley, although they might in theory have made use of at least four others, leading in quite different directions. This evolutionary peculiarity was due to cultural affinities between two particular isolates of mountain-dwellers.

GENETICS AND THE DEMOGRAPHIC MINIMUM

It has been shown recently that the concept of the isolate, adopted by population genetics, is inseparable from the concept of the minimum population, which is purely demographic. This idea of minimum population poses the problem of the demographic minimum, which we may call the problem of Livi, the Italian demographer. In his work on demography, Livi put forward a biological concept of population. In his opinion, the form of association between the elements of a population is conditioned by the biological characters of the species in question. The sex ratio,[1] the period of growth, the average life expectancy, the duration of fertility and of gestation, the number of births per litter and the physical characteristics of the offspring —all these factors determine the social forms of marriage, of the family and of the group. This universal tendency assumes a particular form in man, owing to his special characteristics, which necessitate exchanges of every kind between a number of individuals in a social group if the species is to be preserved. It is therefore important to know what numerical size a group must have to ensure the biological preservation of the species.

Study of statistics for a number of decadent societies shows that, generally speaking, the excessive splitting-up of a human group leads to its disappearance. Too sharp a numerical decline inevitably upsets the balance in sex and age group distribution, as well as reducing the safety margin in the proportion between the competent and the incompetent, between producers and consumers. Experience shows that small groups, consisting of a mere few hundred individuals, with the high fertility and mortality characteristic of archaic populations, are doomed in time to die out.

Although he did not give exact figures for the minimum population, Livi writes: 'Study of the demographic conditions of small, isolated territories has led to the conclusion that demographic stabilization and continuity are ensured only when the population exceeds 500 persons. Isolated groups

1. The number of males per 100 females.

ranging from 300 to 500 inhabitants seem to exist in a state of disequilibrium which will result either in the attainment of stability or in rapid extinction.'[1] It is interesting to note that this demographic minimum is roughly the same as the figure given by Dahlberg for the size of isolates in a country of pre-industrial Europe, namely, 400 persons. The agreement is not accidental; these previous populations had gradually found their demographic and social equilibrium, by breaking up into small, independent groups. This comparison enables us to grasp the full importance of numerical size in the establishment of a society capable of acquiring characteristics that will ensure its survival.

The phenomenon described above might, at first sight, seem purely demographic in nature, a simple numerical fact, quite unrelated to population genetics. Yet it takes on a deeper meaning if it is considered in relation to the latter. Studies by Sewall Wright, Haldane and Malécot have, in fact, proved the importance of size in the genetic constitution of small populations.

In large populations, whose numerical size tends to be unlimited in the mathematical sense, the proportion of the various alleles remains the same from generation to generation, according to Hardy's formula. Populations of limited size, on the other hand, necessarily tend towards a homoallelic structure. Marriages between heterozygous individuals are inevitably commoner, and the production of homozygotes is considerably increased. Individual genetic structures become homogeneous in populations of this kind —with all the practical consequences this entails so far as variations are concerned.

It is understandable that, in a small population, the frequency of a gene will not remain constant, but will 'drift at random within the range of possible values' (L'Héritier). In each generation the frequency of certain genes may thus be expected to increase at the expense of their alleles. In the course of these successive modifications, and assuming that the genes in question are not subject to mutation, it is possible that some of them may be finally lost to the population. The absence of the blood group B among the Amerindian peoples of North America is accounted for in this way. It is generally agreed that the Amerindians came from Asia in small groups, across the Bering Strait. Since the frequency of group B individuals, most of whom are heterozygotes, should be about 10 per cent, this characteristic is, of course, easily threatened with extinction within a group of 100 persons. The hazards of reproduction and gene fluctuations make it clear that group B would thus easily disappear as a result of drift.

If, in the same circumstances, the genes are subject to mutation, without being subject to any selection pressure, we can realize the importance of accident or drift in small populations. To cite L'Héritier again, 'It is clear

1. L. Livi, 'Considérations théoriques et pratiques sur le concept de "Minimum de population",' *Population*, 1949, 4, p. 754-6.

that in the absence of selection, genetic drift is a factor of considerable importance, and also that relatively small changes in the mutation rate or in the size of the population may result in enormous modifications in the distribution of gene frequencies.' We may conclude that even when selective factors are present, the size of the population remains an important element in establishing its genetic constitution.

In the light of these facts, we see how important numerical size has been, during the course of human history, in determining the biological characteristics of peoples.

THE INFLUENCE OF SOCIAL INSTITUTIONS

We have seen the close and inevitable link between the numerical size of populations and their biological characteristics. This conclusion is not new, but our knowledge of this important fact has been clarified in theory, if not yet in practice, by population genetics. Everything which affects the numerical size of a population also affects its quality, and hence its biological characteristics. As we shall see later, this fact will certainly contribute in future towards a more exact understanding of the phenomenon of race. Before discussing this point, however, we must dwell on another aspect of populations which can help to clarify our ideas concerning the process of evolution of human societies.

When we look at the chief man-made factors affecting population, those having a truly decisive influence on all its various aspects, our attention is first drawn to the legal regulations governing marriage and consanguinity. C. Lévi-Strauss recently published a comprehensive analysis of the subject. The reader is struck first and foremost by the enormous variety of laws and customs governing this vital aspect of social structure, in all populations alike.[1] On every continent, within every race, from tribe to tribe and from group to group, there are often radical differences between the laws governing marriage.

Lévi-Strauss has discussed at length, from the point of view of preventing incest, the merits of these systems, as well as the moral principles which probably underlie them all. Whether the systems imposed by law are historic and irrational in their origins, or whether they are due to the deliberate intent of legislators, hardly concerns us here. What we do wish to emphasize is the patent fact that many of these rules are a deterrent—and sometimes a very serious deterrent—to population growth. Whatever the motives for prohibiting certain marriages, they must usually have had an appreciable demographic effect. When we think that the early human race consisted of a

1. C. Lévi-Strauss, *Les Structures élémentaires de la parenté*, Paris, 1954.

very limited number of individuals, grouped in small communities, it is clear that the problem of numerical size was vital for them. Their very survival, precarious in any event, was seriously endangered by their marital laws, if these were ill-suited to their way of life.

We could point to many specific examples of rules of consanguinity which discourage population growth, but shall merely cite a few simple cases. The apparently fairly general rule of matrilateral marriage, i.e. marriage with the daughter of a mother's brother, rather than with the daughter of a father's sister, must have its effects on the marriage rate. These effects would vary, *a priori,* according to the size of the isolate and the average size of families, but are bound to be appreciable in small groups. The ban in certain primitive groups on marriages between cousins of the fifth degree (i.e. between cousins once removed) rules out any marriage between the children of two different generations, and the effect is more serious in a population with large families of, say, five children. It automatically reduces the marriage rate and is a deterrent to numerical growth.

However, it should not be thought that these circumstances are peculiar to primitive populations; they are very definitely at work even in present-day societies. For instance, the ban imposed by the Catholic Church on marriages between close blood relations is clearly not based on biological considerations; it is in fact a vestige of the Mosaic Law, which must have afforded a means of maintaining strict patriarchal control over families in which many couples had to live together in promiscuity. The Church at present prohibits marriages up to the sixth degree of relationship, and in doing so opposes its own objective of a high marriage rate. If it did not in fact grant dispensations for such marriages, it would seriously reduce the marriage rate. We shall cite only two examples drawn from an earlier study. Between 1919 and 1929, 22 per cent of the marriages on the Island of Sein, in France (1,200 inhabitants) fell within the ban of prohibited degrees, while in the much larger town of Crozon (9,000 inhabitants) the figure was 17 per cent. Rigorous intervention by the Church would have substantially reduced the marriage rate and would have had a serious effect on the demographic status of the area.

Human society cannot be regarded as a natural population, comparable to other animal populations, whose development and breeding seem to be largely determined by chance. The fact that man is a conscious being and that he issues moral decrees—in other words, the fact that he has a social constitution—has far-reaching repercussions on his biological development. The human factor is superimposed on the biological and environmental hazards to which every population is exposed as regards its development and preservation.

It may be assumed, from biometric data supplied by population genetics, that many isolated populations must have died out in the course of history,

simply because the development of their sociological structure and of their moral edicts hindered their growth and condemned them to biological extinction. The recent extinction of a number of Australian tribes, which has surprised demographers and ethnographers alike, should be reconsidered from this point of view.

Groups which have been reduced by this process have necessarily been forced to link up with others whose institutions have at least favoured or even directly caused satisfactory demographic development. The small groups, in such cases, have had to give up the characteristics of their culture and accept those of the stronger group. We may note that this phenomenon has had fortunate consequences from the genetic point of view, since this absorption, even of small numbers, could only serve to increase the genetic variability of the larger population. It is thus understandable that legal systems favouring demographic growth have easily and quickly ousted others. The better adapted their cultural institutions are to man, the better chance groups have of increasing their numerical size, of expanding and conquering territory. A numerical example given by Pearson is sufficient to show the importance of this phenomenon at the demographic level. Let us take a population consisting of two isolates, living side by side. Twenty-five per cent of the total number of families are included in one of these, their fertility being such that they produce 50 per cent of the total number of children in the two isolates. In the second generation, their descendants will make up 78 per cent of the whole population, and, in the third, 98 per cent. This is a striking demonstration of the importance of the differential fertility which may result from differences in institutions.

PROBLEMS OF ECOLOGY

We have so far shown, on the basis of simple genetic and demographic considerations, that there can be no useful study of societies which does not take into account all specifically human factors. Numerical size affects the biological structure of individuals and of societies but is in turn controlled by their laws. Population genetics can contribute much towards an understanding of the relationship between these simultaneous influences and of the part they play in shaping the characteristics of a population. Only this study, together with demography, can yield an adequate interpretation of many basic phenomena, since it can view them as a whole and measure their implications.

Since institutions are an important factor in these vital phenomena, the extent to which individual and group psychology, in various cultural settings, may react upon the caracteristics of the population can readily be imagined. The study of these simultaneous and often reciprocal influences does in fact

cover the whole field of modern sociology. Population genetics, therefore, should sooner or later provide substantial technical aid to sociological research. It will suffice, as an example, to discuss here that branch of sociology which has had most frequent recourse to mathematical techniques—ecology.

Of the many definitions of ecology that have been given, the following is felt to be appropriate in this context: 'It is the study of the distribution and movement of individuals, groups and institutions in the physical and social environment, and of their mutual relations.' It is clear that such a field offers the most fruitful soil for the elaboration of mathematical theories and the widest applications of statistics.

Following MacKenzie's initial work, the distribution of individuals in various geographical areas has given rise to several ecological studies.[1] R. Gibrat has shown that, according to the 1926 census, the distribution of French towns with more than 5,000 inhabitants followed a simple mathematical law, which was the same for the big cities of Europe and North America. Rashevsky, using a different method, later obtained the same results in the United States of America. Thus, according to the 1940 census, the distribution of communities with more than 3,000 inhabitants in the State of New Hampshire can be adequately represented by a first-degree function. According to Rashevsky's calculations, the distribution of the rural population, in relation to the urban population, must follow strict laws. We can see at once the close relationship between these principles and those discussed above in connexion with the isolate and its problems. This is also the subject-matter of population genetics.

This community of purpose becomes still more obvious if we examine the concepts subsequently arrived at by the ecologists, through Burgess' research on large American cities, for example.[2] We speak of a *natural area,* for the natural ecological zones defined by the sociologists do not coincide with administrative divisions. The distribution of homes, of political opinions, even of criminality, often overflows the artificial boundaries of organized zones. Again, in ecology, the term *dominance* is used to express the fact that many influences, shaping society and social relations, derive from one central source. The concept of *gradient,* which is included among these influences, has been borrowed direct from biology. It is clear that ecological sociology must have close contact with the biological sciences. And if we look closely into its problems, we can see that if they are to be satisfactorily solved, there must be close co-operation in future between genetics and demography. On perusing a work like *Middletown,* by R. S. and H. M. Lynd, one is struck by the extent to which adoption at the outset of a biological plan would have given a different orientation to this study of a town and its inhabitans, or at least a more sound structural basis.

1. Cf. M. Alves Martins, *Uma nova concepçào da ecologio humana,* Lisbon, 1952.
2. Cf. A. Cuvillier, *Manuel de sociologie,* Paris, 1950.

GENETICS AND ANTHROPOLOGY

Anthropology is a field in which the science of population genetics has overthrown a number of classic ideas and in which its findings are bound to have far-reaching repercussions. We shall confine our remarks to physical anthropology, with special reference to matters concerning race and the definition of race. The very fact that so many definitions have been given is a clear illustration of the difficulties experienced by anthropologists in trying to settle on one. They were recently unable to agree upon a general definition which would include all the most appropriate terms. A large number of them, including Kluckhohn, finally acknowledged that the term had little scientific utility—an assertion which was wise in the light of modern genetic research.

Indeed, how can we help viewing with amazement and scepticism all the anthropological research and thought which has been expended, for example, on identifying the origins of the human race? This is a survival of a pre-Mendelian view which clear thinkers, such as Dahlberg, have long since seen in its true light. Dobzhanski has also aptly condemned this type of attitude, the futility of which is obvious.

Whatever definition is given of the human race, and whatever ulterior motives have consciously or unconsciously guided scientists and philosophers in discussing this question, it should be recognized that before proceeding any further we must consider man in his original environment. The anthropologist who speaks of race is really referring to groups, social units, or associations between groups of individuals. Once we accept this fact, it is easy to understand how population genetics, by imposing stricter methods, disproved and overthrew ideas so often marked by confusion and sentimentality. This is a major achievement in a field which, in the form of racism, has affected humanity so much in recent decades.

The concept of race, from the genetic standpoint, implies the action of a series of mechanisms which will imprint particular biological characteristics on primitive society. This concept can only take shape if we think of what can happen to a small group of people living in isolation. We have seen that the problem is primarily one of demography: the foremost concern is to ensure the subsistence and then the survival of the group; and we have seen how legal, moral and religious rules may influence this subsistence and survival.

The development of the biological qualities of the group depends first and foremost on its numerical size and is at the mercy of chance (genetic drift). Mutation, selection and migration simultaneously play their separate roles, each of which may be equally important and decisive. It is easy to see how mutation, within relatively few generations, may result in the establishment of qualities which an anthropologist later would define as racial.

To take a concrete case, let us consider the role which might be played by such a selective factor as malaria in the geographical concentration of highly pigmented individuals. It has been observed that the boundaries of the black 'race' coincide very closely with those of the malaria regions. This fact has been confirmed by numerous studies of the varying degrees of resistance to malaria possessed by different races. Dark-skinned peoples (melanoderms) are, as a rule, more resistant to this parasite than the fair-skinned peoples (leucoderms). However we account for this different resistance, it cannot be denied that it is an important selective factor. Peoples enjoying an inherent racial tolerance of malaria have a geographical distribution different from that of others.

L. C. Brumpt[1] has gathered some interesting data on this question. The same rule apparently governs the distribution of dark and of light-skinned Indians; that of Negroes and Amerindians in countries of varying altitudes such as Colombia; that of Annamites and Mois in Indochina, etc. Moreover, in the case of the Amerindians and Negroes of South America, malaria is allied with pneumonia in determining the areas inhabited by the two peoples. The Negroes keep to the lowest regions, which are also the hottest; for in the far cooler mountainous areas they are exposed to pneumonia, to which they have poor resistance, their organisms being specially vulnerable to the pneumococcus. The Amerindians, on the other hand, have a high resistance to this disease, whereas they are very sensitive to malaria in the hot low-lying regions. Selective factors of this kind have undoubtedly played an important role in gene distribution throughout history.

The recent study of the genetic structures causing sickle-cell anaemia has shed light on the mechanism underlying the foregoing factors. In this form of anaemia, heterozygotes have red blood corpuscles shaped like sickles. Homozygotes also have this type of corpuscle, but in addition they suffer from an anaemia which is frequently fatal during the first years of life.

It has been established that heterozygotes suffer less commonly and less severely from malaria than do individuals who are homozygous with regard to both alleles.[2]. The proportion of individuals in the population who are carriers of the falciform corpuscles is therefore the result of a balance between two factors: (a) the severity of malaria, which tends to increase the frequency of the gene, and (b) the rate at which the homozygotes are eliminated, that is, the proportion of individuals dying of falciform anaemia. On the whole, the heterozygotes are far more likely to survive and to reproduce than either group of homozygotes. Allison, in a study of 25 African tribes, showed that among the tribes afflicted by endemic malaria the percentage of individual carriers of the gene is invariably higher than 10 per cent, while it is always

1. L. C. Brumpt, 'Les différences raciales de comportement à l'égard des parasitoses,' *Sem. Hop.*, 1952, 28, p. 717-20.
2. A. C. Allison, 'Notes on sickle-cell polymorphism', *Ann. Human Gen.*, 1954. 19, p. 39-51.

less than 10 per cent in tribes where malaria does not exist or occurs only during epidemics. Among the most exposed populations, the proportion of heterozygotes is about 40 per cent, when the point of equilibrium is reached. The same phenomenon has been noted in Greece and India.

The foregoing example is important for more than one reason. So far as pure biology is concerned, it is actually the first time that the existence of the phenomenon of heterosis (hybrid vigour),[1] which has often been noted among plants and animals, has been clearly demonstrated in man. But the demonstration was immediately found to have a more far-reaching implication. When replaced in the context of population genetics, this finding makes it possible to understand how a single selective factor may determine the genetic constitution of a people. In the case of malaria, we have already noted the differentiation between the leucoderms and melanoderms. We now see how heterosis may differentiate secondary groups among the melanoderms. This is important; among other things, it enables us to calculate the speed of transformation of two originally analogous populations which are separated geographically, by migration for example, so that one of them is exposed to malaria; and to visualize the effect of a local prevalence of malaria or of its spread to new areas.

There have been historical instances of these phenomena, the operation of which has not previously been understood. We know, for example, that a very isolated tribe in southern Morocco, consisting of leucoderms, numbered 100,000 individuals at the beginning of the eighteenth century. The number today has dropped to 10,000. Doctors in Morocco have attributed this numerical decline to the fact that the tribe's camping area has been progressively invaded by malaria during the last two centuries.

The example of sickle-cell anaemia illustrates the rapidity with which the characteristics of a population may change when subjected to selective pressure; but it should also remind anthropologists that phenomena of this kind must be more widespread than is ordinarily supposed. As a rule, heterozygotes are more resistant than homozygotes, and the idea has often been put forward that this may have an effect on the characteristics of a human population. Individuals for whom phenyl-thio-carbamide has a bitter taste ought to be more resistant to certain selective pressures, as R. S. Fisher has theoretically demonstrated.

Finally, the inference of Allison's phenomenon cannot be fully grasped unless it is considered in relation to the major concerns of modern genetics. Its full meaning should be discosed by new studies of problems raised by the phenomena of association (Haldane) and by the existence of *linkage*.

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1. Heterosis means the capacity which a hybrid may possess of having one or more characteristics not in its parents' make-up. It is presumed that this is due to a special combination of recessive and dominant genes. Individuals manifesting this phenomenon are invariably more vigorous than either parent.

THE IMPLICATIONS OF HARDY'S FORMULA

One of the basic contributions of population genetics, as we have seen, is the Hardy formula. This formula makes it possible to understand not only the facts cited, and the possibilities they imply, but also the morphological evolution of groups and the differentiations which may eventually appear within each of them. Yet it is unfortunate that the meaning of this formula should hitherto have been all too often misconstrued by the anthropologists who have wished to make use of it. The principal reason for these errors appears to be a misunderstanding of the importance of one basic factor—the gene frequency.

To understand the part played by this factor, we only need to refer to the effects of consanguinity. Marriages of consanguinity are harmful mainly because they encourage the appearance of individuals who are homozygous with respect to recessive degenerative genes. As distinct from dominant genes, recessive genes produce their effect only in homozygous form, or, one might say, when they appear in a double dose. We can easily see that the more uncommon a recessive gene is, the more chance it has of manifesting itself through such marriages as these, since the chances that both parents will have the same gene, at two corresponding *loci* in their gametes, are greatly increased. This explains why, among the victims of rare or relatively rare malformations, we always find a high proportion of individuals born of marriages between cousins, a proportion amounting to 17 per cent in the case of albinism, 23 per cent in the case of ichthyosis, etc.

S. M. Jacob was the first, in 1911, to construct mathematical models explaining the importance of this phenomenon in a population. His figures have been verified by observation. One of his models gives the relative proportions of individuals with abnormalities due to recessive genes resulting from marriages between cousins, on the one hand, and from all marriages on the other. Figures are given for frequencies of marriages between first cousins, ranging from 1 per cent to 5 per cent of the total number of marriages. If the anomaly occurs with a frequency of 4 per cent to 5 per cent in the population as a whole, the non-consanguineous marriages produce more than twice as many abnormal individuals as the consanguineous marriages. But if the anomaly has a frequency of 1 per cent, this ratio is reversed. The differences actually show a sharp increase as the frequency of the anomaly diminishes. Thus, in the case of albinism, which occurs once in every 20,000 of the population, marriages between cousins, assuming a range of 1 per cent to 5 per cent, will produce from 20 to 25 times as many albinos as the non-consanguineous marriages. In the case of very rare anomalies—such as those constituted by the Laurence-Moon-Biedl-Bardet syndrome, which occurs once in every million individuals—consanguineous matings produce from 226 to 801 times as many cases as the others.

Consanguinity therefore helps us to understand how the differentiation of characters in the population of an isolate is determined by the latter's size, and to what degree this, in turn, will determine the gene frequency. It is then understandable why the Hardy formula applies especially to common genes, but not to rare gene frequencies.

Incidentally, we might point out that the study of factors others than consanguinity leads to the same conclusions. Study of the results of homogamy is particularly instructive in this regard. Homogamy is said to exist when preferential marriages take place in the population, that is, when individuals having the same characteristics intermarry more frequently than mere chance would dictate. In this connexion, the factor which has been most closely studied in man is height: tall people have a definite tendency to intermarry. A certain degree of homogamy has also been noted in relation to hair and eye colour, intelligence quotient, etc. It has been demonstrated in theory 'that in homogeneous human populations, an appreciable homogamy as to height goes with a particular distribution of blood groups, thus affording good proof of the Hardy formula. This may well be the case if the differences between the average heights corresponding to the various blood groups are very slight' (Malécot).

It has been shown, then, that the size of the group scarcely affects the distribution of certain very common genes, but does have a very marked influence on the distribution of other genes. The effect of the isolate may be detected from the distribution of genes as widespread as those of the commonest blood groups. But the percentage of individuals possessing one or another of these genes shows little variation, as the interesting studies by Fraser-Roberts have shown. The differences between the respective percentages of individuals having different combinations of the AB groups and of the O group are never as large as those we observe in relation to rarer characters.

It seems, on the basis of these essential facts, that isolates, or rather the isolation of the most primitive groups, even if they remained numerically small over a long period, never succeeded in bringing about any far-reaching changes in the most widespread characters, which are also the most fundamental characters of the species. The differentiation of characters which gave rise to 'races' has therefore never resulted, in man, in observable differentiations such as could create fundamental differences between the races. Thus the changes have never reached such a degree as to make sexual relations impossible between different human groups. Sexual difference has never reached the extent observable among birds, for example. However, while the fundamental qualities of the race have in this way been able to maintain an apparent perenniality, this has not been the case with other qualities—such as the colour of the skin, the nature of the hair, and other morphological characteristics of secondary importance—which have had relatively little

influence on the species and the development of the group as a whole.

This must be due to the richness of the human genom, that is, to the great variety of genes it contains. The genetic patrimony of mankind may be likened to a deep mass of water in a prismatic vase, resting on its broad base. The lower layers contain the most common genes; then, as we approach the surface, we find layers, of equal thickness, containing genes of increasing rarity. Under the influence of factors mentioned earlier, the surface of the genetic mass may be troubled by waves of varying height. But, however tall they may be, the trough of the waves will never reach very far down, and only the surface shows the differentiations upon which the concept of race is built. We must remember, then, that racial differentiation in man has affected only a certain group of genes.

The Hardy formula helps us towards a logical understanding of the creation of racial groups, in the sense used by anthropologists. It gives us a quantitative grasp of the phenomena which have determined racial characteristics. This is an obvious advance over all earlier concepts. As we now know that the two types of human characteristics, somatic and psychic, are due to the activity of a large number of genes distributed widely among populations (e.g. height and intelligence), we should not be surprised at our failure to find fundamental analytical differences between the basic qualities of different human groups.

Modern statistical analysis shows up the absurdity of earlier attempts to prove that height, or this or that intellectual aptitude, existing in a group, can be considered as a specific racial characteristic. J. B. S. Haldane has shown the futility of this type of reasoning.[1] The fact that curves for height or for an aptitude, among two 'racially' different populations, always cross one another, corroborates what we have said above, as to the lessons to be drawn from the Hardy formula. The most far-reaching selections have not been able to differentiate true races, doubtless because the basic mass of the genom is impervious to even the deepest perturbations. It is the common biological possession of all men, wherever they may be and whatever may be their degree of evolution.

The present study, incomplete though it may be, should have given some idea of the relationships between the various scientific disciplines concerned with the study of man. That the biological sciences should be able to produce such repercussions upon all the social sciences is a relatively recent finding of the greatest importance. Professor Westergaard recently wrote, in this publication: 'Some day it will probably be realized that one of the most important scientific achievements of this century has been the formulation of the modern theory of biological inheritance, known as the "gene-chromo-

1. J. B. S. Haldane, *Heredity and Politics*, London, New York, 1938.

some theory". For it will be seen that this theory has revolutionized not only the biological sciences, but also technology, medicine and even the humanities'.[1] In the course of its development, Mendelian genetics has periodically produced reactions of opinion which have not always been limited to the domain of science. It would certainly not have been able to produce such profound reactions if it had not begun to overthrow so many deeply-rooted ideas.

In our time, a radical re-examination of received ideas on which scientists have been building since the middle of the nineteenth century is taking place. The sciences concerned with man are particularly affected by this phenomenon, which has broken down the laboriously constructed boundaries erected by earlier generations. It is gratifying to see that Mendelian genetics is playing an important part in this process of development, which constitutes, in the words of P. Teilhard de Chardin, 'a significant forward step of modern thought in its irresistible advance towards a unified body of knowledge'.

1. *Impact*, Vol. VI, No. 2, June 1955, p. 63.

REPORTS AND DOCUMENTS

NATIONAL RESEARCH COUNCILS AND SCIENCE POLICY

by

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This paper was presented at the meeting of directors of national research councils, held at Milan from 15 to 19 April 1955 at the invitation of Unesco. The author, a physicist who worked formerly in German industry, is now a member of the Department of Natural Sciences at Unesco.

INTRODUCTION

National research councils can be defined as governmental bodies or private organizations sponsored or recognized by their governments, responsible for the promotion of scientific research. As always on the international level, such a general definition has to embrace a bewildering variety of forms. But in spite of the many differences of structure, working methods, the varying emphasis on pure or applied science and the varying range of influence in their respective countries, the common feature of all these councils is their aim to promote research. This aim is based on the recognition that scientific research and the increase of knowledge are of the utmost importance for the well-being of the community. Whilst some councils exist only to promote, stimulate or encourage scientific research, others have as their purpose also the control, direction and co-ordination of research. In the majority of councils the statement of the aims and purposes contains an explicit reference to the benefit that is expected for the development of national industries, especially where the council emphasizes applied research; only a few of them are devoted to the promotion of purely scientific studies without regard for further development.

UNESCO AND THE COUNCILS

Of the 74 Member States of Unesco about 30 have one or more national organizations working for the promotion of scientific research. Most of these have been established since 1945, though generally, in the scientifically advanced countries of Europe and North America, some kind of organization on the national level had been started in the period after the first world war.

Since only about one-half of the Member States of Unesco as yet have a national research council, it seems worth while to discuss the question whether the establishment of such organizations would be of benefit to the

other Member States. This in turn raises the issue whether organization 'from the top' can replace the organic growth of a research movement starting at the level of individual universities and industrial laboratories. There is a natural tendency in the more developed countries to answer this question negatively. But it all depends on the policy pursued by the respective governments, and the structure they have given to the organizations which actually put this policy into effect.

The proposition that scientific research cannot very well be promoted by organization 'from the top' is based on the historical development in the advanced countries, where scientific research was at first a university preoccupation—notwithstanding the contributions made to scientific knowledge by outsiders of genius like Faraday. Universities were generally founded long before it was realized what tremendous impact scientific research would have on society, and long before it became necessary to organize science for increased efficiency. But this was not the case in the less developed countries. Here, if one compares the foundation dates of universities with those of research centres, there is a much smaller time interval; but it is clear that organization, though it cannot be a substitute for a system that has grown up organically, can speed up scientific development both in its educational and technological aspects. Therefore the national research councils in these countries have a more creative task to perform and a relatively more important role to play than in advanced countries where a fund of experimental knowledge, highly qualified scientific manpower and material equipment already exist and call rather for co-ordination and intermittent financial support than for direct control. It is hoped that some discussion on this point will bring forth suggestions and comments in the light of which Unesco will be better able to advise on the establishment of such councils.

TYPES OF COUNCIL

Whilst there is a large measure of agreement on aims and purposes, detailed discussion of policies presupposes knowledge of the framework for the execution of policy. There is no need to go into much detail about the variety of organizational and administrative structures, as these have already been described elsewhere.[1] The organization of applied research has also been extensively described in a report published by the Organization for European Economic Co-operation.[2] Nevertheless a very brief summary of the main types of organization comprised under the title 'National Research Council'

1. See *Survey of National Scientific Research Councils*, Unesco/NS/122, April 1955.
2. *The Organization of Applied Research in Europe, the United States and Canada*, Paris, OEEC, 1954.

is useful at this point, because it will bring out most of the points for further discussion.

There is first of all what may be called the foundation type of organization, which derives its income chiefly from an initial endowment and which promotes research by giving grants and subventions to qualified scientists, or scholarships and fellowships to students and other research workers who have not yet completed their training. Examples of this type are the Fonds national de la recherche scientifique in Belgium and the Fonds national suisse de la recherche scientifique. Of all the councils under consideration, this type of organization is least subject to government control. It does not own or control any laboratories, nor does it officially advise the government on matters of science policy.

Then there are councils whose income depends on a regular grant from the government but which are free to dispose of these funds within the limits of their programme. They usually do not own or operate laboratories but provide funds for equipment, grants for specific research projects, assistance to publications, travel grants and scholarships, etc. Examples are the Danish State General Research Foundation, the German Research Association, the Swedish Natural Science Research Council, the National Academy of Science-National Research Council in the U.S.A.

However, the majority of national institutions for the promotion of research are closely connected with the government, not only because they administer government funds, but also because they are supervised and controlled by some government department, though they operate their own laboratories and actively direct research with clearly defined plans and programmes.

A roughly similar classification will be obtained if one considers the main activities of these various institutions. The organizations of the first group restrict themselves to the granting of subventions, fellowships and scholarships, with occasional grants for special equipment. But although their executive action may thus seem limited, their programme usually embraces all fields of learning and tends to emphasize fundamental research.

In the second group, the programme is usually a little more ambitious. For example, the activities of the German Research Association comprise the formation of expert commissions and working parties to study specific subjects by means of conferences and symposia in order to plan and co-ordinate practical research work in a given field, the allocation of grants to scientists for equipment, travel, publications and auxiliary staffs, procuring of foreign scientific publications for university and state libraries, and assistance to training of research workers by means of fellowships. Here, too, all fields of learning are supported.

But it is with the last group, in particular, that the activities assigned to the research councils come to have more direct bearing on the conditions of life in the respective country. One example will suffice to indicate the scope

of the tasks set before them. In answer to the questionnaire sent to the various councils on the occasion of the survey, the Pakistan Council of Scientific and Industrial Research mentioned the following as its main activities: '(a) the initiation, promotion and guidance of scientific and industrial research having a bearing on problems connected with the establishment and development of industries or with any other allied matter referred to the council by the Central Government; (b) to establish or develop national institutions for research, with the object of utilizing the economic resources of the country in the best possible manner; (c) to make grants-in-aid for specific research schemes at universities and other research institutions in Pakistan; (d) to undertake and foster developmental research for the utilization of discoveries and inventions resulting from researches of the council; (e) the establishment and award of research fellowships; (f) the collection and dissemination of information on scientific and industrial matters and the publication of scientific reports and periodicals relating to the activities of the council; (g) to encourage the establishment of industrial research associations by various industries; (h) to maintain contacts with industrial research organizations in other countries.'

ADVISORY COUNCILS

The above examples have been chosen more or less at random; and the classification is by no means to be taken as rigid or clear-cut. The purpose was to show that the role each council can play will vary from country to country. Only a few of the councils have as one of their explicit purposes the formulation of science policy or the role of official adviser to the government on matters concerning scientific research. Perhaps the formulation of science policy has been a later development, most councils having been created to meet a practical need. The establishment of the Department of Scientific and Industrial Research in the United Kingdom during World War I is perhaps the most striking example of this, and it was in Great Britain that the need for continued advice and guidance on policy first led to the establishment of the Advisory Council on Scientific Research whose function it is 'to advise the Lord President of the Council in the exercise of his responsibilities for the formulation and execution of government scientific policy'. The Advisory Council was established in 1947, whereas the Department of Scientific and Industrial Research has been in existence since 1916. In any case, as the various councils, centres or other national organizations for the promotion of research expand their work, they will, regardless of their structure or responsibilities, inevitably be faced with certain problems which require a policy decision. And as the funds contributed by the governments increase, such policy decisions may eventually be made on the ministerial level rather

than by the governing body of the respective council—though the council will nevertheless have a decisive influence through its advice. There will furthermore always be certain recurrent problems on which decisions will have to be made in the light of changes in the overall situation and as new needs arise. This need for an advisory body is being recognized more and more—as the establishment of a Conseil supérieur de la recherche scientifique in France shows.

POLICY DECISIONS

Fundamental Research and Application of Research Results

Probably the most important policy decision is whether emphasis should be placed on basic (fundamental) studies, or on what generally goes by the name of applied research. There has been, and still is, some controversy about a clear definition of what constitutes fundamental and what should be called applied research. It is not the intention of this paper either to revive the controversy or to try to make a new and rigorous definition. The sub-title above suggests a definition which might come closer to reality in so far as applied research usually means a study of how to make use of facts previously uncovered by fundamental research.

The problem as stated at the beginning—emphasis on fundamental or applied research—does not exist in countries like Belgium, Denmark, the Netherlands, Norway or Sweden, because they have established separate councils for the two fields. Nor was the decision to create two councils necessarily made by the government; rather, the councils were created to meet an actual need—possibly at the suggestion of groups outside the government. But it is now a question of national science policy whether one research council should deal with all fields of learning, or whether there are to be several councils. It might be argued that to have several councils covering different fields entails an exaggerated administrative machinery, since much of the processing and financial control of subventions or grants could be handled by the same staff in a central office.

In countries with only one council the constitution of the organization sometimes prejudges this question whether emphasis should be placed on basic or applied research. It declares the purpose to be the promotion of research 'with a view especially to its application to trade and industry,' or 'to create and develop favourable conditions for the scientific and technical progress of the country and to stimulate and promote scientific research for the benefit of the nation'. But although most of the experts are agreed that the various types of research—basic or fundamental, pure or applied, background or technological—are not amenable to clear-cut, universally accepted

definitions, it is safe to say that those who have to make the final decisions in the council or who have to do the planning for research will, in spite of the lack of clear-cut definitions, usually have no trouble in determining to which type a given project belongs.

All this suggests that the statement made at the beginning of this section, viz. the importance of a policy decision as to emphasis on fundamental or applied research, is redundant. But whenever a council is called upon to formulate explicitly a national policy for scientific research, whether or not it will actually put this policy into effect itself, it will have to consider the elementary truth that fundamental research is at the basis of all so-called applied research. It will also have to consider that fundamental research into principles has its own intrinsic value. The words basic or fundamental research are here used to cover only those studies which, though they have knowledge as their object, nevertheless differ from 'pure' research inasmuch as the knowledge will, it is hoped, prove useful. This restriction is necessary in view of the fact that the bulk of the funds of the councils comes from the governments. It is meant to exclude studies of less significance, such as investigations on the theoretical explanation of empirically established industrial processes or instruments in terms of known mathematical principles or relations. There are evidently many subjects on which basic research could be done involving much scientific skill and ingenuity but producing relatively little advance for either theory or practice. It will be one of the councils' main functions to separate these from the studies that deserve support on account either of their usefulness or of their importance for the acquisition of new knowledge and understanding.

Once the criterion of usefulness is introduced, there will of course be a strong bias in favour of applied research, which is perhaps best illustrated by the proportion of research workers devoted to fundamental as against applied research. For 1951 this was estimated as 1 : 2 for the United Kingdom and as 1 : 4 for the U.S.A. The annual budgets of the separate councils for pure and applied research will show a similar bias in favour of applied research. Vannevar Bush in his famous report pointed out the danger that applied research was likely to drive out basic research.[1] And this is not only a question of government policy. As Alan T. Waterman, director of the U.S. National Science Foundation, says in a recent article: 'To us in the National Science Foundation it has been clear from the very beginning that the nature of basic research is far from being understood by the American people. At a critical juncture in our history, when much of our future may depend upon the soundness and originality of our basic research, the tendency has been to hold its support to an absolute minimum.'[2]

1. Vannevar Bush, *Science the Endless Frontier*, Report to the President, Washington, D.C., 1945.
2. *The Scientific Monthly*, January 1955, p. 13.

A secondary aspect of this policy decision concerns the connexion between the universities and fundamental research. In Europe it has long been taken for granted that fundamental research rightly and properly belongs to the universities. The success of this system is evident and should not be open to doubt. Yet there is a tendency to keep fundamental research secret because of its military importance. Furthermore, a research council may be tempted to neglect fundamental research as being a university activity anyway. The decision on how and where to support fundamental research may thus have some incidence on the educational system of a country.

Creation of a Suitable Intellectual Climate

The quotation towards the end of the last section brings up a second important point. It should be one of the main functions of a research council to create a generally more favourable attitude towards scientific research and a better understanding of what scientists can do and what they cannot do. In many countries people are prone to blame scientists for the sombre prospects created by atomic energy, forgetting that scientists very often have little or no influence on political decisions. This must be borne in mind when deciding how the council or the government might set about creating greater receptivity for the ideal behind scientific discoveries. A great deal of the popularization of science tends to be excessively sensational and fanciful. Perhaps the council will decide to extend its subventions to good books popularizing science without too much loss of scientific rigour. Or perhaps it could work more indirectly by supporting science courses in adult education institutions and the like. There will be manifold opportunities for such work in the various countries, and whilst some countries are very research-conscious as regards technological advancement, the importance of fundamental studies may not be fully realized.

The councils might also take over some clearing-house functions for the spreading and dissemination of information on scientific development, personnel news, reports on symposia, etc. Much of this is of course being done already, and some countries have valuable experience in these directions.

Scientific Manpower

Another matter to which research councils will periodically have to pay attention is the problem of an adequate supply of scientific manpower for the research needs of the country. As the problem of status and career of the research worker is dealt with in another paper,[1] the only aspect which needs to be considered with relation to the formulation of a national science

1. See the report on the career of the research worker, in the next article in this issue.

policy is that of education and training. In a booklet published by Unesco[1] the need for 'organized social foresight' was pointed out. Such foresight was to be exercised by all those concerned with education, by using the best knowledge available to provide for educational facilities in relation to technological needs. In this matter research councils can again play an important role, for although they are unlikely to have much direct influence on the curricula of the universities or technological colleges and the like, they can do a great deal by means of periodical surveys to assess shortages or surpluses of certain categories of specialists. The council can then determine its policy for allocation of scholarships and fellowships in such a way as to counteract undesirable trends. It may even go to the length of issuing public statements on the manpower supply problem, though it would doubtlessly be better to work out a long-term policy by providing the possibility of rewarding careers in science.

The situation in India is a good example of the importance of the manpower problem. In that country a rapid economic and technological development is likely to be severely hampered by the lack of sufficient numbers of trained scientists and engineers, as the great majority of students now in the universities and colleges have chosen law and the humanities rather than natural science. Perhaps in this case it is more a question of creating the suitable intellectual climate than of introducing counteracting measures. But in any case, it is a matter for a policy decision by the council. Experience with the Colombo Plan also seems to suggest that before being really able to benefit from technical experts, the underdeveloped countries must dispose of a body of competent trained technicians available locally. Even more specifically, the council may have to advise on measures to counteract a shortage of science teachers. As a basis for policy decision in this field, the council might decide to set up a scientific and technical register of personnel engaged in research—as is already being done in some countries.

Emphasis on Special Fields

New problems that arise, or shifts of emphasis on certain research subjects, are another matter for policy decisions. There are certain subjects which momentarily attract the greatest attention because of the revolutionary changes to which research on them may lead. In some cases one might almost speak of a fashion—witness the many applications of information theory. But since the funds of a research council are usually rather limited, it may be necessary to establish certain priorities, quite apart from the choice between fundamental or applied research. The question is whether funds shall be distributed evenly to all areas of research that fall within the council's

1. *Education in a Technological Society*, Paris, Unesco, 1952.

competence, or whether certain subjects shall receive preference in the allocation of subventions or grants. Some councils have already established such a special priority programme apart from their regular work. Thus the German Research Association has given special grants for research projects on radiology, medical and biological studies on viruses, microbiology, computers, genetics, and certain topics of agricultural interest.

In the technically less developed countries such emphasis may be put on research on the exploitation of local raw materials or on the ways and means by which local farming can be improved, since technical assistance alone cannot solve all these problems. If the council is not restricted to the natural sciences it may devote some funds to the support of such projects as demographic studies, for example. In fact the councils in those countries will be faced with sociological problems arising out of industrialization which will call for another policy decision as to whether they should include such problems in their own programmes or whether they should advise the government on them.

In the highly industrialized countries similar problems will arise. For instance, the practical applications of the results of studies pursued under the general heading 'cybernetics' have been described as a second industrial revolution. Labour unions have tended to regard the introduction of ever more automatic machinery with concern. This whole problem may as yet be acute in only one or two countries; nevertheless it will become increasingly important in all industrialized countries. Some councils support the development of large-scale computers only as mathematical tools of fundamental research, but the wider perspective of the problem would also merit a policy decision.

Project Research

The question of whether to subsidize research projects or competent scientists also merits attention. Some councils vigorously oppose project research, insisting that support should be given to well-known scientists rather than to some specific programme. Undoubtedly project research has certain disadvantages. There is the danger that experimental design may take precedence over ideas, that the application for support gives too much detail about the experimental procedure and too little about the personality of the applicant. There is the question of reporting on progress, and the duration of grants. But these are problems of actual financing rather than questions of policy. If it is decided to sponsor project research, the policy most likely to be successful would seem to be for the council to state the general subjects it wishes to support, and to invite specific applications from competent institutions or individuals.

Establishment of Laboratories

The problems considered in the last two sections take on a slightly different aspect if the council possesses its own laboratories. About one-half of the existing national research councils have laboratories of their own. Most of these are specialized in some particular subject; thus the question of emphasis does not arise directly. Indirectly, however, it arises through the distribution of the annual budget of the council.

With some experience of previous allocations, the director of the laboratory will usually be able to draft a good programme for research. The case will be different where the laboratory is, for example, a national physical laboratory. Here the establishment of a programme for research will not only take into account the equipment and personnel available, but also be subject to long-term policy decisions of the director and the research council. Research on atomic energy is a case in point. Quite a number of countries have created or will be creating separate commissions or departments for atomic energy on which the research council has relatively little influence.

One point seems certain. A research council of a technically and scientifically less developed country, if it has its own laboratories, is likely to absorb a far greater relative proportion of the national budget for research, and its decisions will have much greater influence on the economic and industrial development of the country. The council may even have at its disposal better research facilities than the industries in that particular country. It may obtain so much government money for the maintenance of its research institutes that the universities may feel slighted. Here the policy decision is evidently a government responsibility. But the council should consider this matter too, for it is in its own interest that a sufficient number of scientists be trained by the universities.

Once the laboratories, specialized or not, are established, there is not too much scope for broad policy decisions by the council. But situations may arise where the establishment of new laboratories appears desirable. The councils should not then be precluded by the rigidity of their constitutions from participating in the planning and establishment of new institutes. Through their knowledge of the scientific developments in the country, they should be able to influence the final decision in the right direction, even if they do not wish to assume direct responsibility for the new institute.

FINANCING

Sources of Funds

The bulk of the financial resources in almost all cases comes from the governments, the most notable exception being Norway where the money

comes from the football pools. Some of the councils were originally established with large endowments to make them independent, but with the depreciation of currencies and as the requirements of modern research have increased, they have come more and more to depend upon their government to supply the necessary funds. Private donations and gifts are still welcome but (with the exception of the U.S.A.) account for only a small percentage of the budget. Support from industry often takes the form of research contracts, grants-in-aid or fellowships for specified subjects.

It may safely be said that the various national research councils would welcome an increase in their annual allocation, or at least an increase in the overall expenditure on research by the government. The arguments with which the council will try to persuade the government to allocate greater sums will often depend on specific projects within the country. Moreover, once the council has been functioning for some years, the annual budget and allocation will be largely a matter of precedent based on established posts, usual requirements for equipment in the laboratories, etc. The more flexible portions, such as the expenditures on scholarships, fellowships, travel and research grants, may however often require tenacious negotiating with treasury officials. But, on the whole, the councils are fairly restricted in their endeavour to have the funds increased. It seems more useful to devote attention to the actual distribution and administration of the actual funds at the disposal of the council.

Modes of Distribution

Wherever the council operates its own laboratories, the bulk of its expenditure will of course go for salaries and investigation costs for the various research projects. Since precedents and established procedures vary from country to country, it is difficult to make universally valid recommendations on this point. One point however deserves to be noted. The directors of the individual laboratories will usually be asked to set up their budget in the light of current projects and of new work due to begin in the budget year under consideration. When it comes to deciding on the requests, the council may want more detail on experimental design than can be clearly foreseen. And this may lead to difficulties or misunderstandings between the laboratory man and the administrator, for even if the administrator in the council's headquarters is a qualified scientist, he obviously cannot be acquainted with all the fields of research covered by the council. Very often a number of laboratories working in related fields are administered by a special division, but the final decision about allocation of funds may not be made by the division itself. The essential point is that as the administrative level at which the decision is made rises, experimental design or excessive detail of projects should not be considered, unless the council wishes to call on expert

committees for advice on the feasibility, etc., of the project submitted. It is of course a question of delegation of authority and mutual good faith, and there is no doubt that an agreement can always be reached by discussion.

The council may also be able to let the respective directors know beforehand what the upper limit of the expected allocation will be. Planning of the year's programme will thus be easier.

If contributions from other sources than the council's own budget are expected, care should be taken that the conditions attached to them are not too rigid, and that the research projects undertaken fall in line with the general programme of the institute. In spite of the apparent increase in administration, it may be advisable to channel such contributions through the national council, unless the laboratories are autonomous with respect to the administration of finance. Once their budget is established, it seems to be more advantageous for the institutes to have such autonomy. Of course, this should not preclude some measure of control to see that the funds are properly devoted to the items foreseen. The director may make transfers between various items, but not reorientate his whole budget.

Councils which do not operate or control laboratories distribute their funds to individuals by way of scholarships and fellowships, travel grants and subventions for publications, support for certain laboratories or sections of laboratories, or grants for research projects limited in time.

The terminology used to describe these various forms of encouragement of research is not standardized, but the general meaning is clear. Three main types of support seem to be current practice with all the councils: (a) grants for continuation or completion of training of research workers; (b) grants to individual scientists for current or future work; (c) project grants.

Of course this classification is not all-inclusive, nor can it be more rigidly defined without making detailed exceptions for the various councils. For purposes of discussion, it will serve to clarify such questions as the amount of its funds that the council will spend on each of these categories in the light of the policy decisions referred to in the previous sections, e.g. if a manpower shortage threatens, the council may have to emphasize the first category, i.e. the training of research workers.

Most of the councils without laboratories award scholarships and fellowships to young research workers, sometimes even on the basis of a hierarchical system. Thus the Belgian Fonds national de la recherche scientifique awards grants and fellowships for the following categories: aspirants—two year scholarships for graduate students; research assignment—two year fellowships on condition that candidate has successfully held scholarship of aspirant category and fulfils certain additional conditions (this fellowship also entails the requirement of six to eight months study in a foreign country); qualified research—two year fellowship on condition that candidate has successfully held fellowship of research assignment category.

Furthermore this council has made it a definite policy to support persons rather than research projects. Of late, the question of post-doctorate grants including a kind of family allowance has become acute, particularly in countries where there is a grave discrepancy between salaries paid for corresponding work in industry and in the universities or even, for that matter, in the laboratories of the national research council. The question is, how long can a research council afford to support research workers without offering them some form of definite employment? A related question is that of selection; here again some councils will have established procedures, acquaintance with which might help newly created organizations.

The grants to individual scientists for their work will usually comprise certain sums for necessary equipment. Where this equipment is very expensive, a different policy may be adopted, the council retaining the ownership of the instruments bought with the grant. The danger here is that requests for assistance will then be framed so as to enable the applicant to retain the instrument as long as possible, even though he is only using it part-time for the studies supported by the council. This applies also to project research—in fact the distinction between project research and grants to individuals is rather artificial, for in deciding on an application for funds the council will always consider the personality of the research worker as well as his proposed subject. The one real difference seems to be that project research is more often than not a matter of team-work though this is not as yet quite so general in the European countries as in the U.S.A.

It would be interesting to compare the proportions devoted respectively to equipment, salaries, maintenance, rents and other charges in the grants allocated by the various councils. These may be different in each case. Some councils, of course, clearly distinguish between grants for equipment, maintenance allowance, travel grants, etc. Separate grants or subventions are usually given for publications; however these are relatively small.

Main Problems

The main problems in each grant or fellowship programme however are: (a) the question of selection; (b) the time limit. As indicated above, some councils have established a complicated, but efficient, machinery to screen the applications submitted. Every effort is made to exclude the possibility of a personal predilection for certain subjects influencing the decision on allocation. Probably the best method would be to submit the applications (endorsed by the director of the institute where the applicant works) to a committee of specialists, and then to the final approving authority. As mentioned above, excessive detail in experimental design cannot be a substitute for ideas, and the council should be able to place trust in the judgment of the scientist who endorses the request emanating from his institute.

The time limit constitutes a problem in so far as in major research projects unforeseen developments or difficulties may often arise. The difficulty for the council often resides in the fact that, its funds being voted annually, it may not be able to carry them over into the following fiscal year. This is again a point of national science policy. Some countries are experimenting with block grants (five-year grants, for example) to the greater research institutes in order to safeguard the continuity of the programme. But treasury officials will always point out that such block grants would conflict with the need for the co-ordination of the whole research and development programme, which can only be effected centrally. Furthermore, government expenditure should be kept reasonably flexible and subject to regular review in the light of changes in the strategic and economic situation of the country.

Thus, the council will have to find a policy which will satisfy the government desire for flexibility, but also maintain sufficient continuity in the work of the institutes it supports.

THE CAREER OF THE RESEARCH WORKER

by

Y. DE HEMPTINNE

This paper was read at the meeting of directors of national research centres, held at Milan from 15 to 19 April 1955 at the invitation of Unesco. The author, who is a biochemist and was formerly head of a special school of technical engineering at Ghent (Belgium), is at present member of the Department of Natural Sciences at Unesco.

INTRODUCTION

Teaching and Scientific Research

Science teaching and scientific research have always been inseparable activities. Indeed, research is a necessary source of inspiration for science teaching, whilst contact with young minds is a valuable asset for the professor engaged in research. These preliminary remarks should make it clear that this study is not a plea for the separation of these traditionally associated activities.

The Research Worker

Research carried out in universities, however vigorous and fruitful it may be, does not suffice to meet the requirements of modern civilization. For this reason, several countries[1] have established a corps of scientific civil servants, who are engaged in research entirely devoted to discovery, invention, or to the solution of precise problems. These research workers are usually attached to a national research centre,[2] or they may be civil servants on the staff of ministries or government departments. Or again, they may belong to private institutions, such as research companies, independent research centres and foundations, research associations and, of course, industrial laboratories.

The Research Worker and National Research Centres

National research centres are mainly responsible for aiding and supplementing fundamental scientific research carried out in universities. In many cases,

1. Canada, France, United Kingdom, United States of America, etc.
2. The word 'centre' is used here in its broad sense, to cover all bodies entrusted with the promotion of scientific research at the national level. These bodies may be either governmental services or private institutions sponsored or recognized by the government.

these centres started with a so-called 'foundation' programme, distributing scholarships and grants to individual research workers in universities and private research institutions (hospitals, institutes, etc.). They were later called upon to help universities whose financial resources were proving inadequate to support research at a suitable level, and did so by means of 'block grants'. Finally, in order to keep up with the development of scientific research throughout the world, they came to have laboratories of their own, sometimes staffed by thousands of research workers. In some countries, on the other hand, the national centres were equipped from the beginning with research laboratories. In others again, a policy of decentralization was followed, the responsibility for organizing scientific research—in so far as research workers were concerned—being entrusted to private institutions (universities, foundations, clinics, etc.) and to various ministries or government departments.

Most research centres, except in the rare cases where there is a separation of functions,[1] are also concerned with applied research. This may be merely subsidized by the council, the research workers being distributed among universities, private laboratories or industrial laboratories; or there may be an agreement between the State and industry for the establishment of research laboratories.

The Research Worker—Career and Professional Status

That the profession of research worker has not everywhere gained official recognition is most clearly evidenced by the difficulty experienced by certain countries in estimating their potential in scientists engaged solely in research. It often happens that research workers are enrolled in other professional categories (e.g. as officials, employees, engineers, etc.), which makes any accurate assessment of their numbers impossible.

However, scientific circles seem to be giving attention to the question of the research worker. The scientific press regularly publishes articles on this subject; it has been touched on at meetings attended by leading experts,[2] and is to be considered at future round-table and international conferences.

On the recommendation of its International Advisory Committee on Research, Unesco therefore took advantage of the exceptional opportunity of a meeting of directors of national research centres to arrange for a wide exchange of views on the career and professional status of the research worker, thereby making a contribution to the study of a question which is of much importance to the future of science.

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1. That is, where there are two research centres, one for pure research and the other for applied research, as for instance in the Netherlands.
2. Conference organized by the Fonds national de la recherche scientifique, Brussels: 'Au service de la science', 27-28 October 1952.

PLACE OF THE PROFESSIONAL RESEARCH WORKER

The Research Worker and the Community

National research centres have been set up in all parts of the world. They all have the same purpose, which is to encourage, promote and co-ordinate scientific research in their respective countries.

Their methods vary widely but may be summed up by this quotation from René Descartes: 'So that if there be someone on earth whom one knew to be capable of making the greatest discoveries and those that could be most useful to mankind, and that for that reason his fellow men were to try every means to help him achieve his aims, I see no other course than to furnish him with the needs for his experiments and, furthermore, to guard against his time being wasted through the importunity of anyone.'[1]

It is curious that mankind should have remained indifferent to this appeal by Descartes for the research worker to receive financial aid from the community and be freed in other respects from any burden likely to distract him from his research.

That the encouragement of scientific research is a matter for which the State is directly or indirectly responsible, is clear to everyone, because the benefits of discoveries accrue to the entire community and because, as Bertrand Russell so rightly says,[2] the investigations are expensive and never certain of achieving any result if taken individually. The foregoing remarks in no way imply that private enterprise cannot contribute to the encouragement of research; on the contrary, they show that the public is aware of the need for research workers and scientists to be provided with the means to enable them to bring work to a successful conclusion.

Place of the Research Worker in the Organization of Scientific Research

In the majority of the advanced countries, the financing of experiments has, since the beginning, been the responsibility of national research centres.

Many appeals were made for the avoidance of any 'commercial' flavour in the financing of research. The public, too easily inclined to the belief that fruitful scientific research can be 'bought', came to think that it was enough to invest increasingly large sums of money in research to arrive at an increasing proportion of positive results.

People were forgetting that scientific research depends on individuals rather than on institutions or organizations. Many national research centres, strong in their belief in the fundamental principle of individual effort in research, have refused and are still refusing to build research laboratories specifically

1. René Descartes, *Discourse on Method*, Part VI.
2. Bertrand Russell, *Principles of Social Reconstruction*, London, 1915, Chap. II.

designed to accommodate research workers, preferring to subsidize the research worker himself.

It is not for us to say here whether this policy is good or bad; each case must be studied in the light of the special conditions in the country under consideration. A weighty argument against the establishment of such research laboratories is the inadvisability of drawing scientists away from universities and other teaching establishments in order to fill research laboratories, thereby causing the sources of qualified research workers within the country to run dry.

Even though account is taken of the above argument, the general trend is nevertheless towards the building of laboratories where scientists and research workers can devote their full time to scientific research.

Some countries prefer an intermediate arrangement whereby research workers, freed from any teaching duties, are staff members of the university department in which they are working, although their salaries are paid by the national research centre. Young research workers thus receive their training in the university from qualified research workers, under whose guidance they work. Freer interchange between teaching and research careers is an advantage of this system, which, for obvious reasons, is often applied in medical research.

Place of the Research Worker in Society

The research worker—whether employed in a research institution or as a member of a research unit in a university, hospital or clinic, or even if engaged on individual research in a university laboratory—belongs to a new professional category.

He cannot remain indifferent to the status he occupies in his society. He can no longer subscribe 'to the narrow views of conservative politicians and demagogues, who would exhort him: go on with your investigations; improve machinery; invent new tools; create more powerful arms—but stay in your laboratory'.[1]

The question of the career and professional status of the research worker, therefore, goes beyond the narrow sphere of material security, this being only a limited—though important—aspect of the problem.

RECOGNITION OF THE PROFESSIONAL STATUS OF THE RESEARCH WORKER

In a paper dealing with the status of the scientist, André Lichnerowicz[2] deplores the fact that social circumstances, money, power and effective

1. F. Mather Kirtley, 'Les nouveaux clercs,' *La Nef*, June 1954.
2. A. Lichnerowicz, 'La condition humaine du savant,' *La Nef*, June 1954.

responsibilities everywhere militate against science as a lifetime career. It must be admitted, as he rightly says, that there is in the world practically no calling to the social summit of which a scientist wishing to continue his scientific work can attain; if he aspires to the highest posts, to carve out a successful career in the eyes of public opinion, he is obliged to become a research administrator, at least.

Some people consider this a satisfactory state of affairs, because they are convinced that only young research workers do really productive work. Would it not be more to the point to wonder why the majority of research workers and scientists, realizing to their cost that a scientific career gains such little recognition, do not yield to the temptations to give up scientific work in favour of administrative, political or other functions?

Unfortunately, they do not all possess administrative ability, and an eminent scientist ought not to be at a financial disadvantage compared with his colleagues who have administrative responsibilities.[1]

Several countries[2] have established in one form or another a corps of scientific civil servants, providing a career with possibilities of promotion for research workers engaged exclusively in scientific research.

In some cases (e.g. the United States of America) these scientific civil servants are assimilated to members of the regular civil service, whilst in others a clear distinction is made. In France, for instance, the State has given research workers a status comparable to that of members of university staffs, specifying, however, that they are not civil servants in the usual sense of the term.[3]

Other countries have not so far taken definite steps in this direction.

Some authorities are against the establishment of a scientific research profession giving too much security of tenure, since this might impede the rigorous selection which guarantees quality in research.[4] According to J. Willems,[5] Director of the Belgian Fonds national de la recherche scientifique, on the other hand, while this rigorous selection undoubtedly confers some advantages on the successful candidates, it lays the less successful open to the risk of a very uncertain future. It may be wondered whether the question of selection arises in countries other than those where there is no lack of qualified scientists and research workers, and whether research administrators are not more concerned with the training and recruitment of scientific staff. The same authority writes: 'Besides outstanding intellectual qualities, besides a clear brain, wide culture and absolute honesty, the young research worker

1. *The Organization of Applied Research in Europe, the United States and Canada.* Report of Technical Assistance Missions 81, 82 and 83, Paris, OEEC, 1954, Vol. I, p. 56.
2. Including Canada, France, Union of South Africa, United Kingdom, United States of America, etc.
3. La Documentation française, *Le Centre national de la recherche scientifique,* Paris, 1952.
4. J. Pretsch, *Symposium on the Organization of Applied Research,* Nancy, 1954, OEEC, Doc. EPA/ST/965/4, p. 13.
5. Brussels Conference, 27-28 October 1952: *Au service de la science,* FNRS publication, p. 130.

needs to possess complementary qualities making him a dynamic and efficient investigator. Except in a few rare cases, people of this calibre have to be caught before they embark on any other career for, once so embarked, they will prove as successful as others similarly gifted and will be reluctant to give up assured prospects. Among each generation of students, therefore, it is necessary to find out those who possess this exceptional combination of abilities. As there is no golden rule for doing so, the only way is to submit candidates who are willing to a probationary period, holding out the attraction of good prospects to those who show outstanding capacities, while at the same time providing reasonable openings for those who do not quite reach the required standards.' Further on we read: '. . . the fear of insecurity must be removed so as to ensure the regular recruitment of reasonable numbers of research workers.' The question of the status of the research worker must therefore be viewed in a light very different from that of the material security which tends to engulf him in routine matters. It affects the recruitment of young people to the scientific profession and, taking a long view, the pace of the advancement of mankind as a whole.

Ought there to be a scientific research profession, the members of which would work their way up as in the army or the magistrature and, once they had joined, would never leave? Apparently not. According to a paper brought out lately by the United States Bureau of Labour Statistics, research workers and scientists are particularly mobile; they change employers several times in the course of a career, often switch from one type of occupation to another, and may even completely change their speciality. This geographical mobility on the part of scientists does not appear to be solely due to the conditions inseparable from the scientific career, but is largely caused by an innate desire for change. It arises from curiosity and a legitimate desire for information and contact with foreign colleagues, to which reference will be made later.

The isolation of scientific research activities is everywhere considered to be a serious mistake, as is made clear in the introduction to this paper. The opinion generally expressed at the International Conference on Medical Research convened by the Council for International Organizations of Medical Sciences (CIOMS) in London, in October 1954, was that there should be a very free exchange of research workers between research institutes and universities, and between teaching and research.

Some delegates to this conference, which was concerned solely with medical research, even held the view that it was not advisable to set up a research 'profession', and that all research workers should teach—not necessarily in the lecture room, but certainly in the laboratory—so as to help train the younger generation.

This is still an open question, but we are reminded of the difficult problem of the engagement of research workers in a second occupation. This ad-

ditional occupation may be a matter of choice, or it may be undertaken to make good the notorious inadequacy of the salaries paid to research workers, or again it may be forced upon them by the shortage of qualified scientists; in any case the problem is much discussed. In some countries the view is even held that the training of young research workers, the preparation of abstracts, the classification and dissemination of knowledge gained in the course of investigations, are tasks of collective interest coming within the professional duties of the research worker, for which he is not, therefore, entitled to receive special remuneration. Research workers in the universities can usually engage in secondary occupations, such as teaching and the training of young research workers. M. H. Trytten,[1] in a report on the career of the scientific civil servant, expresses the opinion that it would be an advantage to research workers employed in governmental laboratories if they could undertake secondary occupations of a similar type.

In conclusion, possibilities of promotion, adequate salaries and the power to continue doing scientific work may prove to be factors of the utmost importance in the establishment of a corps of research workers, as is evidenced by the recent examples of the Department of Scientific and Industrial Research (DSIR) in the United Kingdom, the Centre national de la recherche scientifique (CNRS) in France, and others.

RESEARCH CLIMATE

In addition to the scientific spirit, characterized by a passion for facts, prudent reserve in making statements, clarity of views and a keen sense of the relations between things, the research worker, if he is to produce good results, needs to work in a definite 'research climate'.

This climate, which is necessary to scientific research,[2] consists not only of the factors of a professional kind referred to above, i.e.: recognition of the research worker's status; possibility of promotion; freedom to engage in non-scientific work (second occupation). It also comprises the factors essential to the research worker's career, namely: freedom to choose and carry out independent studies; possibility of doing interesting and worth-while work; free access to scientific information and to the work that others may have done before him; an atmosphere conducive to creative scientific work, etc.

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1. M. H. Trytten, *The Scientist as a Government Employee*. Report prepared by the Interdepartmental United States Advisory Committee on Scientific Personnel for the President's Scientific Research Board, Washington, D.C., September 1947.
2. See J. R. Steelman, *Science and Public Policy*, Washington, D.C., October 1947, Vol. III, Chap. VII.

Freedom to Choose and Carry out Independent Studies

We are here concerned with qualified research workers, not with beginners completing a period of training in scientific research after obtaining their university degree.

Freedom in the selection of the subject of research is closely connected with the method of financing and with the general policy of the particular country in regard to scientific research.[1] From the point of view of freedom in the choice and carrying out of investigations, research workers may be divided into the three following categories.

Research workers attached to universities. These usually enjoy the freedom customary in university institutions in the selection and carrying out of their investigations. The same is not true of the members of a team. As Charles Kidd[2] somewhat cynically observes, freedom of choice and of execution is most often invoked by people who are themselves very dictatorial in their relations with those whose research they supervise and direct. Nothing is more disastrous for a young research worker than the impression that he is a mere tool in the hands of a research co-ordinator, whose guiding idea he can never fathom. An interesting paper by T. Shapiro[3] shows that this is one of the reasons why research workers and scientists leave their posts.

The question of team-work hardly arises in connexion with theoretical studies, which are usually individual; on the other hand, it is acute in connexion with experimental research, which is generally conducted by groups. The question of individual or collective research has for long been disputed. It should, however, be recognized that research conducted by teams has produced remarkable results in the experimental sciences. According to David E. Green,[4] the question is no longer whether team research is necessary in this field, but what type of team research produces the best results. Agreement has thus been reached on the principle, and it seems that the solution of individual cases may be found in the organization and administration of research in the universities.

Research workers employed by the laboratories of national research councils. These do not have complete freedom in the choice of subject for their investigations. The choice is usually left to the directors of the laboratories, but the workers have considerable latitude in the conduct of the research. The same difficulties with regard to team-work occur here. On the other hand, it is permissible to think that the establishment of a profession of

1. The question of financing and of general policy with regard to scientific research are the subject of Mr. Moller's report in this issue.
2. Charles Kidd, 'Scientists and Administrators', *Science*, 7 August 1953.
3. T. Shapiro, What Scientists look for in their Jobs, *Scientific Monthly*, June 1953.
4. D. E. Green, *Science*, 2 April 1954, p. 445.

research worker, with appropriate grades and offering possibilities of promotion, as in France, Canada and elsewhere, is conducive both to better human relations and to improved working conditions.

Research workers employed in State laboratories usually have the subject —and sometimes even the programme—of research imposed on them by the government. They accept this restriction of their freedom of action because of the compensations they receive in the form of higher salaries. (Research workers in industrial laboratories are in a similar position.)

In short, this classification of research workers according to the degree of freedom they enjoy in the choice and execution of their investigations is only a round-about way of putting the difficult question whether aid should be given to the project or to the man. Each country puts forward its own solution to this problem. There is general agreement, however, with the statement made by A. von Muralt, President of the Swiss National Research Council, that 'it is contrary to the fundamental law of science to impose programmes and to try to direct scientific discovery'.[1]

To what extent is it possible to depart from this policy in respect of technical and applied research, and what line of conduct should the national research centres follow in the matter? These, again, are much debated questions.

Possibility of doing Interesting and Worth-while Work

By this is meant: (a) that the research worker shall be provided with the resources required for effective research (subventions and apparatus); (b) that he shall not be distracted from his research work by other tasks, such as administrative duties.

The question of subventions for research work and of the equipment of laboratories is outside the scope of this report. The question of the use of research assistants, on the other hand, is of particular importance, since this is a method of increasing the output of highly-qualified scientists.

This problem of research assistants was one of the original reasons for the establishment of research laboratories by national research centres and government departments. The research worker engaged on individual research in a university often has difficulty in procuring assistance, for such assistance cannot readily be justified from the financial point of view.

When a research worker is attached to a university department he always receives open and cordial hospitality on the scientific side. Difficulties mostly arise in connexion with administrative matters or with technical assistants,

1. A von Muralt, *Science and Government*, Report to Unesco, unpublished.

whose services are competed for by the various sections of the laboratory. The research worker then sometimes finds himself obliged to construct his own apparatus and to keep accounts (often somewhat unorthodox) of the expenses incurred in connexion with his work, for submission to the national research centre.

Some universities have solved the problem by the creation of a pool of auxiliary personnel and technical assistants, as a result of which the routine difficulties arising from the temporary presence of outside research workers are much less felt.

In any case, the question of research assistants directly affects the working conditions of research workers and should be carefully considered.

In regard to technical and applied research, the problem of the development of research workers' inventions should not be overlooked. The term 'development' covers the operations of perfecting, manufacture of prototypes and production in a pilot plant. Nothing is more distressing to a research worker than to see the results of his work proving an industrial failure because they have been badly applied. Setbacks of this kind do him harm, even though he is not responsible for them. His investigations will be of practical value only if they are applied with the most scrupulous care. It is generally agreed that, if the cost of research is taken as the unit, development and production in a pilot plant require ten times that amount, and a hundred times that amount for industrial production to begin.

Whilst it is clear that responsibility for financing research proper lies with the laboratories, associations or national research centres, and that for financing industrial production lies with industry, the importance of the services rendered by this technical development should not be overlooked, nor should its cost be under-estimated. It is only on this condition that the possibility of doing worth-while work can come within the reach of the research worker employed in technical research. Several countries go even further in their efforts to safeguard the interests of the research worker by putting a patent service at his disposal. According to the case, the proceeds of the patent go to the research worker either in whole or in part. Another method is to take out the patent in the name of the national research centre, which makes over part of the proceeds to the inventor. This latter system has the advantage of not injuring those research workers who are engaged in tasks involving no likelihood of remunerative inventions.

Access to Scientific Information

This subject is too vast to be dealt with, even superficially, in the present paper. We shall therefore deliberately confine our remarks to the possible influence of this question on the career and status of the research worker.

It is surely unnecessary to stress the need for supplying the research worker

with information on the work that others may have done before him. Libraries, documentation centres, scientific periodicals, abstracting bulletins, microfilms, etc., have become indispensable tools without which it is difficult to imagine any work being undertaken. The problems of semantics, discussed by J. E. Holmstrom[1] in an article on the languages used in scientific publications, are not overlooked by the research worker who is anxious to be well informed.

The results of some investigations are not published, for reasons of military security, etc. It is not for us to discuss the reasons for this practice or whether it is justified. It is, however, a fact that it tends to slow down the advancement of science and, according to certain leading scientists, fails utterly to achieve its purpose—rather the contrary. It is understandable that research workers who are deprived of the just reward of having their work published should feel frustrated, and that those who find that what they have been striving to discover has apparently been discovered long ago by others, should feel discouraged.

It is generally admitted that the spirit, technique and general background of recent scientific advances cannot be acquired by reading alone. For this reason the national research centres have endeavoured, by every possible means, to increase personal contacts between research workers and their colleagues, whether of the same nationality or not. Round table discussions, congresses and exchanges of research workers are organized. In some countries, indeed, the grant of subventions to certain categories of research workers is conditional on a prior stay of several months in laboratories or teaching establishments abroad.[2]

The publication of scientific works of merit is the final stage in the process of research. The national research centres usually subsidize the printing and publication of studies intended for a restricted audience of specialists, which do not find their way into the world scientific press.

Atmosphere conducive to Scientific Research

A careful study of the careers of some of the great scientists reveals that, to produce an atmosphere favourable to creative scientific work, yet other factors are required, particularly of a moral, affective or emotional kind. Research workers and scientists are trained in an atmosphere of complete intellectual freedom. Their minds develop according to the tradition, methods and doctrine of scientific accuracy, scepticism and criticism, without which no progress is possible. They cannot accustom their mind to follow previously mapped out paths, for they possess the pioneering spirit.

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1. J. E. Holmstrom, 'The Language Problem of Science,' *Research*, May 1954, p. 190-5.
2. This is the case of the Fonds national de la recherche scientifique in Belgium.

It is not for nothing that Pavlov stressed the need for an emotional climate of confidence, freedom and happiness for creative scientific work, and Descartes the importance to the research worker of not having his time wasted by other people—a condition which he himself, alas, was never able to achieve.

This problem is of little concern to young research workers, but it may become of crucial importance to those occupying important positions in the scientific world.